EXERCISES IN
HUMAN PHYSIOLOGY

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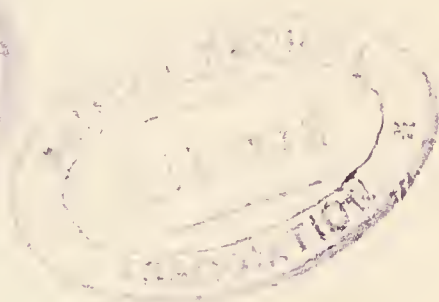# EXERCISES IN HUMAN PHYSIOLOGY

(PREPARATORY TO CLINICAL WORK)

BY

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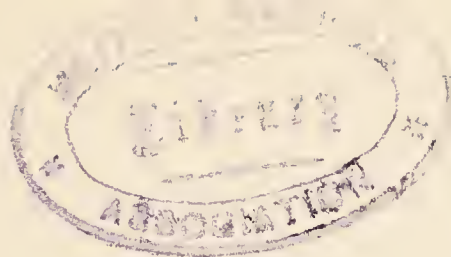MACMILLAN AND CO., LIMITED
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PREFACE

FOR many years I have held the view that the transition from preclinical to clinical studies is the most difficult period through which medical students have to pass. It is difficult because it is a change from the deliberate and scientific ways of academic study to those of hospital life, governed as this constantly is by the urge to succour sick people. The student, accustomed to contemplate the tissues and functions of organs systematically, to measure accurately, to reason precisely, is suddenly confronted with numberless, complex, and obscure problems, and with the necessity of at once resolving these by the readiest means available. There is an abrupt passage to a foreign atmosphere, where speed of work is increased, where opportunism reigns with the voice of authority, where memory is more extolled than reason, and where therefore the value of earlier teaching is from the first obscured. Although, as the years pass, hospital practice becomes more and more influenced by the sciences ancillary to it, and is increasingly affected by rational argument, yet the differences between two methods of thought are, and will remain, conspicuous ; and the passage from one to the other will continue to be both too quick and too bewildering unless deliberately controlled.

The desirable bridge has seemed to me to be the bridge of human physiology. I advocate the much fuller teaching of human physiology in the last preclinical phase, and the introduction of precisely apposite classes of clinical science in the earliest stage of the final work, so that applications of physiology to the problem of human disease may be witnessed and impressed as soon as the student sets foot in hospital. He should enter the hospital more highly trained than he now does to handle human material, and to use upon

man methods with which the laboratory has already made him familiar ; and thus it would be made manifest to him from the beginning how appropriate is the preclinical to clinical work.

In advocating and discussing what has here been outlined, it has been pointed out to me that there is no published work which would suffice to guide the classes proposed. Naturally I am aware of the great work of Haldane and his disciples and of the introduction of much of this work on respiratory exchange into physiological classes ; I am also aware of other recent efforts to extend the educational use of human physiology, as by Lythgoe's *Practical Physiology of the Sense Organs*. Nevertheless these notable efforts are insufficient for two reasons. Firstly, because many of the exercises now in use—and which I trust will continue to be used in general physiological classes—entail technical methods that to be serviceable require long and frequent practice, and that cannot be utilised in clinical work by the generality of students. And secondly, because exercises at present available cover too narrow a field.

The field of work should be widened and it is probably necessary that the clinician should largely guide the selection of exercises. Perhaps I possess a limited qualification to do so, having as a clinician sought out simple applications of physiological knowledge for so many years. At all events it has weighed upon my mind that I may not remain in the position of giving lip service to an idea, and not attempt to contribute something substantial to its working. Because I think it right that exercises should be arranged only by those who have themselves thoroughly tested, understood, and applied them, it becomes evident that, like others who have preceded me, I cannot satisfactorily cover the whole field. Thus the exercises here given should be regarded, not as completely covering the useful range, but only as the contribution that I personally feel competent to make. But I

believe that the cardiovascular system, being a thing of movement, and the cutaneous system, being superficial, will always provide a large proportion of the most suitable exercises.

It should not be thought that I regard all the exercises set down as necessary ; experience will show which are the most attractive and useful ; some teachers may prefer to adopt this or that selection. I must be content to remark that all are tests that I have found instructive or directly valuable in my own clinical work. Some will prefer to depute the responsibility for exercises like ulnar anaesthesia to surgical colleagues ; the procedures are all simple, but, as in this instance, surgical cleanliness is sometimes required and should be strict ; in this circumstance none carries risk. For those who are sufficiently interested I have added occasional references to original papers providing channels of further information.

Lastly, it has been remarked to me that present day physiological class rooms are not arranged so that students can form themselves into a number of small groups around couches in quiet surroundings. This difficulty could be met in part by selecting exercises, in part by different groups carrying out the same exercises at different times. When the value of these or similar exercises is established, as I have little doubt it will be in the future, the form of the class room will not be allowed indefinitely to postpone their use.

CONTENTS

1. VISIBLE VASCULAR PULSATION

In normal young people at rest the only vessels which move the skin at all freely are certain veins ; it is unusual for normal arteries to show visible pulsation, and then it is but slight. This is so because when veins pulsate the volume change is large, whereas in the case of arteries the volume change is almost negligible ; it is not until an artery is pressed upon that its wall excurses appreciably.

Do not neglect the following exercises because they seem simple and some of them obvious. You will in the future see pulsations (normal or otherwise) in patients, but you will never experience a better opportunity of finding out what the normal pulsations are like.

Ask the subject to lie supine on a couch with head resting on a single pillow, with arms, neck, and chest exposed.

1a. *The arms.* Inspect the wrist where the radial artery lies ; the inner side of the upper arm where lies the brachial artery. The courses of these arteries cannot be traced by pulsation.

1b. *The neck.* The only pulsation you are likely to see in the neck is venous.[1] The subclavian artery along the clavicle and the carotid artery in the carotid triangle are easily felt if pressed upon, but their pulsations do not usually move the skin. But there is nearly always visible pulsation, and often large pulsation, at the root of the neck. When, as often, the external jugular vein is large and superficial it forms a prominent cord to the zero level of venous pressure (see p. 7); and it pulsates maximally here and down the vein a little toward the clavicle. In such an instance the maximal pulsation can be made to appear more distally by raising the foot

[1] *B.M.J.*, 1930, 1, 849.

of the couch, and to approach the clavicle by raising the head of the couch. Place a finger very gently on the skin over the pulsation and note, however large, that it is so soft that you can hardly feel it. The pulsation is large because it is happening in a vein under very little tension, consequently a slight increase or decrease of pressure in it changes it to an almost full or empty vein. If you take away the pillow and raise the foot of the couch much, the vein will become turgid to the angle of the jaw and it will be so tense that little pulsation can occur in it.

Notice the character of the venous pulse where it excurses maximally ; this is a fluctuating movement, consisting of two or three distinct rapidly succeeding waves at each beat of the heart.

1c. *Deep venous pulse.* In subjects in whom the external jugular vein is not prominent, deeper venous pulsation is usually to be seen. The place to look for it is between the two heads of origin of the sternomastoid muscle ; often it moves the belly of this muscle a little higher up ; sometimes it moves the whole base of the neck. This deep movement is always to be seen to some extent in young normal people lying at rest ; often it is a very big movement ; but a finger laid lightly upon it hardly perceives it. It has the same complexity of form as the external jugular pulse, and as with this its position can be moved up or down the neck by change of posture.

1d. *Precordial impulse.* The heart's impulse will usually be visible and palpable, confined to a short length of the 5th space, with its outer margin 8 to 10 cm. from the middle line. Exceptionally it may be in the 4th space, or in 4th and 5th ; or, when the subject is spare, in the 3rd to 5th spaces (diffuse impulse).

Ask the subject to roll onto the right side ; the impulse

will move towards the sternum and will sometimes disappear beneath it. Ask the subject to roll onto the left side; the impulse will travel out an inch or more towards the axilla. The normal heart is thus shown to be mobile.

The normal impulse varies in prominence, but is usually a little thrusting, though not a very well sustained movement, in systole. It is abolished when respiration is held in inspiration.

1e. *Epigastric pulse.* Examine the epigastric region and often you will find it slightly shaken by each beat of the heart. The movement is not a strong one and usually consists of a little recession in systole.

Application

The distinction between arterial and venous pulsation is of very great importance in many patients, for both arterial and venous pulses may be abnormal. It requires attentive study before the distinction can be made without error. It is a mistake to think the distinction always easy; most of those who fail are those who have not studied pulsations in normal subjects.

Arterial pulsations become visible in arterial disease, and when arterial pulsation is excessive, for example when the aortic valves are leaking badly.

When there is no visible vein in the neck, the level of maximal venous pulsation is used in heart affections to measure venous pressure. Venous pulsation is seen only in the cervical veins normally, but in abnormal conditions it may occur in the arms. It is lost in the neck in clotting of the superior vena cava.

The position and character of the cardiac impulse is our most valuable bedside guide to the size and position of the heart. It is highly important therefore to be familiar with the normal impulse. Mobility of the impulse is lost when the heart is tied by inflammatory adhesions.

2. RECORDING PULSATIONS

2a. *Method.* The art of polygraph work [1] consists in having a machine in good working order, the subject properly placed, and in being deliberate and precise in your other procedures. Before you begin make sure that the tambours do not leak, that the venous membrane is just slack and the arterial membrane tenser, that the pens write easily and in good alignment, and that the arterial pelotte is connected to the tambour which lies farthest from the time marker.

The subject should lie supine, relaxed, with right arm and neck (and for cardiac impulse chest) fully exposed. The head should be propped on one or at the most two small pillows.

2b. *Arterial curve.* First extend the subject's right arm fully and let the back of the elbow rest on the edge of the couch or on your knee, the forearm being thus kept extended under its own weight. Find the brachial pulse at the tendon of the biceps and strap the pelotte directly and firmly over it, taking up slack with the adjusting screw. Do this with the sliding valve on the pelotte open. Now close the valve and the pen should move. Secure a short strip of arterial curve. If you have done aright and the arm remains tautly extended and still, the pen will not leave its level on the paper. Start the time marker and see that it writes.

2c. *Venous curve.* Now add a venous curve. The subject's head should be so arranged on the pillow that the neck is flaccid, the chin inclined a little to the left, and venous pulsation obvious at the root of the neck. You should rarely start before you can see clearly the movement you desire to

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[1] The polygraph here referred to is the author's modification of Mackenzie's instrument (see *The Mechanism and Graphic Registration of the Heart Beat*, London, 1925).

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record. A few good curves are taken in the subclavian triangle, but more are obtained over the internal jugular vein, over or just central to the lower part of the sternomastoid muscle above its tendon. The lower you are on the neck the more respiration will bother you. Keep the venous pen off the paper at first. Pick up the receiving cup, between thumb and index finger, slip your middle finger a little beyond the edge of the cup and gently press cup and finger down over the place where you see suitable pulsation ; when you have pressed the tissues down a little, slip your middle finger slowly away and the soft tissues will follow it and close the remainder of the cup's mouth. The venous lever should now begin its movements and the pen can be brought on to the paper next to the time marker. You will learn by experience that it is often wisest to keep a little away from the biggest pulse you can see. The right is preferable to the left side of the neck. When all three pens are moving and in place on the paper, start the paper running ; if the record is coming satisfactorily, ask the subject to stop the breathing gently at the end of ordinary expiration. This will eliminate inconvenient respiratory excursions from the venous curve. Unhurriedly stop the clock while the curves are writing straight and, immediately index marks are written, start it again before too much ink runs into these.

Measure off the distance of a brachial upstroke to the index mark horizontally (Fig. 1) and transfer this measure from venous index mark to venous curve. It will bring you to a point on the latter, about 1/10 second to the right of (behind in point of time) the upstroke of the " c " wave. The " a " wave, usually less conspicuous, will lie to the left and the " v " wave to the right of this. You now have a timed record indicating the normal pressure events in the right auricle.

2d. *Carotid curve.* Now attempt with the cup receiver to obtain the carotid curve. The carotid pulse can be felt along

the border of the sternomastoid ; use heavier pressure on the receiver, to get down to the artery before you close the mouth of the cup. You should be able to obtain simultaneous curves of carotid and radial pulsations, both writing
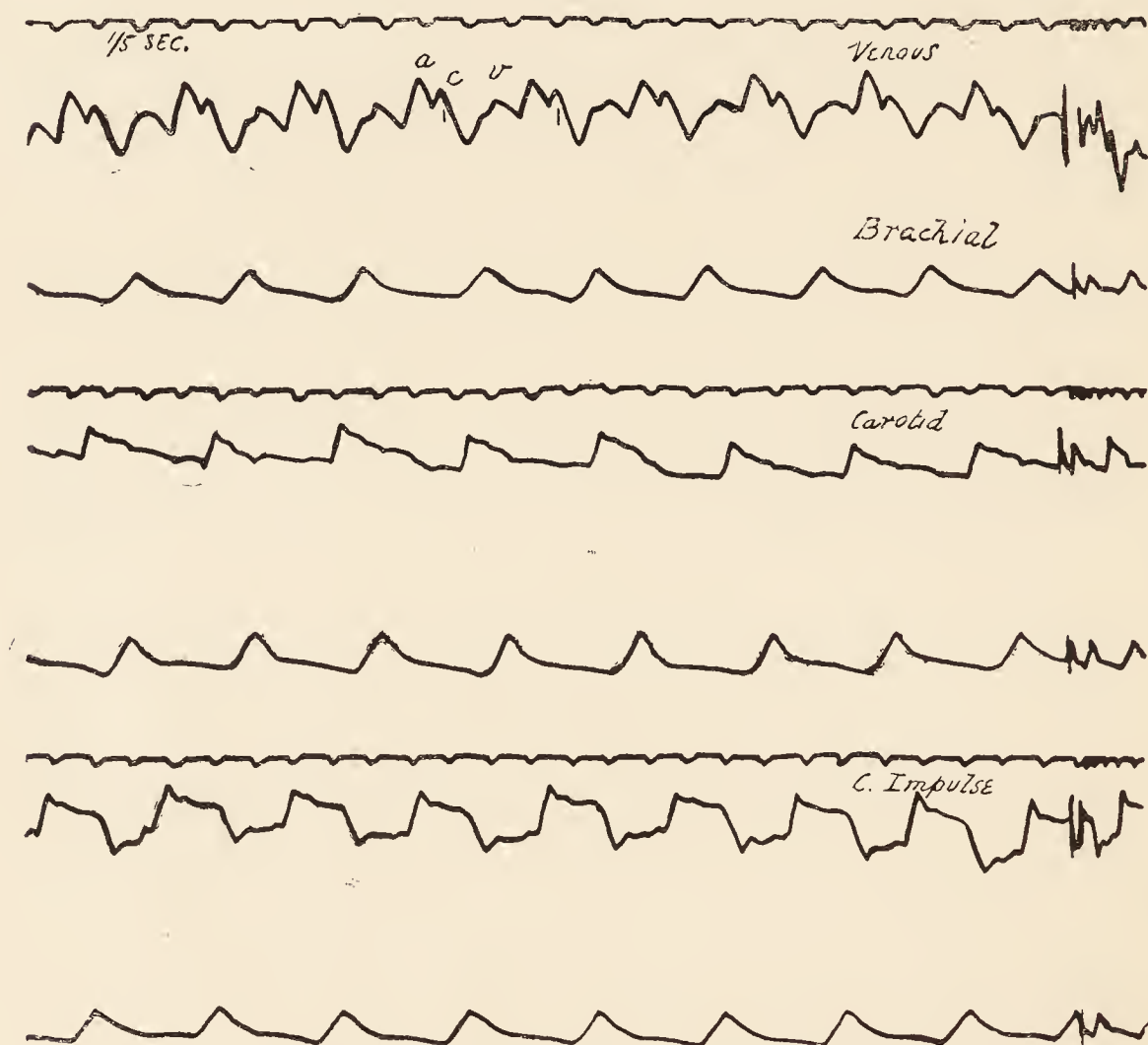
FIG. 1. ($\frac{3}{5}$ nat. size, approx.). Three tracings taken in quick succession from a normal subject. Each has time marker at top and brachial curve at bottom. Simultaneously with these venous, carotid, and cardiac impulse, have been taken in the three tracings respectively. Index marks allow relative timing in all.

straight on the paper. When you have these and the corresponding index marks, you can ascertain that the delay between carotid and brachial upstroke is about 1/10 second, as it is between " c " wave of the venous and radial upstroke.

2e. *Cardiac impulse.* If the impulse is prominent, you

will have no difficulty in recording it, using the cup receiver. The subject may lie a little on the left side, advantageously. The upstroke precedes the brachial upstroke by about 1/5 second, this includes the presphygmic interval and arterial transmission time.

Application

These simultaneous records are valuable for many purposes, allowing the pulsations in various parts of the body to be timed. They are chiefly used to study disordered heart mechanism, as when the relation between auricular and ventricular systoles is disturbed. There are no forms of irregular heart action which may not be identified by this method.

3. BLOOD PRESSURE READINGS

Blood pressure readings taken by sphygmomanometer from normal subjects in the manner described are known to be reliable within the range of small errors. They have been compared in man with direct manometric readings from the corresponding artery.

3a. *Apparatus.* The armlet or cuff used must answer certain requirements. For an upper arm of usual dimensions, the rubber bag should have a width not less than 12 cm. and it should have a length allowing it to encircle the arm completely (21 cm. or more) ; the much shorter bags now in frequent use in hospitals are unsound. The bag's covering should be of relatively non-extensible material.

3b. *Systolic pressure by palpation.* The subject should lie supine with chest and arms unclothed, the observer sitting

near the subject's right hip. Wrap the armlet around the right upper arm, placing the centre of the rubber bag over the brachial artery and keeping it as high on the upper arm as it will go. It should be wrapped, not tightly, but so snugly that it will not slip down the arm ; and it should be wrapped very neatly, so as to support the distended pneumatic pad uniformly. Feel the radial pulse and, keeping your left fingers on it, raise the pressure in the cuff well above the point at which the pulse disappears ; this safe obliterating pressure will be to about 160 mm. Hg in most normal subjects. Open the valve a little and allow the mercury column to fall steadily and not too slowly, until you feel the first beat of the returning pulse ; note this systolic reading, and check it by repetition.

3c. *Auscultatory readings.*[1] Now bring the subject's elbow to rest upon your knee, so that the relaxed forearm is kept fully extended by its own weight. Ascertain the position of the brachial pulsation in the region of the tendon of the biceps muscle, mark it precisely, and press the bell of your stethoscope over this pulsation. Done in this way there is little chance of the vessel moving away from the stethoscope and the sounds will be well heard. There should be an interval of not less than 2 inches between the bell and the lower edge of the cuff ; it is for this reason that the cuff must be placed high on the upper arm. Now raise and gradually lower the cuff pressure in the manner previously described. The dull thud of the first pulsation to pass through the cuff will give the reading of *systolic pressure*, and this should be similar to that from the radial pulse by feel. If it differs it will usually be a few millimetres higher than the latter reading.

As the mercury column falls, the sounds will become louder, more prolonged and murmuring ; then, remaining

[1] Korotkow, Berl. d. k. Milit. Akad. St. Petersb., 1905, 12, 395.

for a time almost unchanged, they begin rather rapidly to decline in intensity, not to reappear again. Occasionally the sounds decline a little in intensity early during the fall of the mercury, to increase again and decrease again finally. In such it is this final decline that is used. The reading corresponding to the beginning of this final decline is the most accurate gauge we possess of *diastolic pressure* in man. Note and repeat the readings.

3d. *Returning bloodflow reading.* The blood pressure can be taken in a different way, the only method available when the pulse is very weak or actually impalpable. Lift the subject's arm vertically to drain the veins, very quickly raise the pressure in the cuff and hold the bloodflow arrested for several minutes. Now lower the pressure in 10 millimetre steps, waiting after each and watching the hand closely for a return of blood to the skin. At a given step the colour change in the skin will be seen and simultaneously the veins on the back of a warm hand will begin to swell. Repeat the test, using steps of 5 millimetres over the crucial range.

While giving a reading for systolic pressure in normal subjects, this method reads *mean* blood pressure in pulseless subjects.

Application

Blood pressure measurements by one or other method described are in constant use in clinical work.

4. RESPIRATION, BLOOD PRESSURE, PULSE, ETC.

4a. *Respiratory movements and arrhythmia.* Normal respiratory movements are performed in part by the intercostal muscles, and in part by the diaphragm. The share taken by the two groups of muscles, differs in different

subjects during quiet breathing; the movements are expressed by lifting of the ribs and expansion of the chest in the one case and by increased prominence of the upper abdomen in the other. Watch these movements in a subject stripped to the waist and watch the effect of a voluntary increase in the depth of respiration; the breathing then becomes more purely thoracic and with each breath accessory muscles, such as the sternomastoids and the muscles of the alae nasi, are called into play.

With deep respiration it is the rule for the pulse rate to increase very obviously in inspiration and to decrease in expiration. In many young subjects there is a lesser " respiratory arrhythmia " with natural quiet breathing.

4b. *Blood pressure and respiration.* Having ascertained the systolic blood pressure reading in a subject lying quietly at rest, fix the cuff pressure near to systolic pressure and ask for deep breaths taken with the chest only. Note that during each inspiration the beats disappear, forcing through the cuff during the succeeding expiration.

The fall of blood pressure during inspiration is due to blood being caught up in the chest during the period of lowered intrathoracic pressure. It can be reversed by breathing heavily with the abdomen, so that at each inspiration the abdominal wall becomes hard; the beats now force through the cuff during inspiration and fail during expiration.[1]

4c. *Pulse lost in inspiration.* The fall of brachial blood pressure during inspiration is not infrequently exaggerated by the subclavian artery becoming compressed during inspiration, where it passes between clavicle and first rib.[2] The phenomenon is clearest when the shoulders are held well back and a deep inspiration is then taken. Even in a

[1] *J. Physiol.*, vol. 37, 233.   [2] *Q.J. Med.*, vol. 8, 38.

small class of students there will be one or more in whom this procedure will bring the pulse of the arm almost if not quite to extinction.

Application

Respiratory arrhythmias are common, normal, and therefore of no pathological significance ; but they may be confused, if they are not recognised, with irregular heart actions of gravity. Similarly blood pressure changes coincident with respiration will be misconstrued if the limits of normal variations are unknown.

5. EFFECTS OF EXERCISE

5a. *Simple exercise test.* Take the pulse rate of a normal young subject who has stood at rest for a few minutes and has taken no vigorous exercise for an hour or more. Note also the rate of respiration.

Now ask the subject to hop easily 20 times on the right and then 20 times on the left foot, the shoulders lifting 6 or 9 inches at each hop. The response is variable, but in normal subjects in or out of training the pulse rate does not rise more than 10 to 30 beats per minute, and the original rate is resumed usually within $\frac{1}{2}$ minute, or at the very most 2 minutes from the end of exercise.

Note also that, although the depth and rate of respiration are a little increased, there is no approach to distress in breathing, and that questions can be answered without sentences being broken or delayed by respiratory movements.

5b. *Strenuous test.* In this test two 10-lb. dumb-bells are used, the subject raising these from the level of his ankles to the full stretch of the arms above the head in one continuous

easy sweep, in time with a metronome and at a rate of one lift every 2 seconds. A healthy young man of sedentary habit, and to that extent " out of condition " can accomplish this lift 30 to 60 times without stopping, but at the end he will show obvious respiratory distress. During the exercise the mouth will very probably open, and at the end of it the alae nasi will be expanding at each inspiration ; respiration will be increased in rate and depth, the hurried breaths will often be noisy, and will interfere with conversation.

This test is useful in comparing the amount of exercise different individuals must take to produce a given and definite amount of respiratory distress. Those in good training will accomplish much more exercise than those out of training. Those in athletic training can continue this exercise for longer periods than those indicated and show comparatively little reaction.

The same test may be used to study the effects of exercise on pulse rate and blood pressure.

The height to which the pulse rises will be found related to the degree of respiratory distress ; when this is considerable, the pulse rate is raised to 150 or 170 beats per minute but it begins to fall at once and quickly when exercise ends and usually returns to its original level within 3 or at most 5 minutes of the end of exercise.

5c. *Blood pressure and strenuous test.* The curve of systolic blood pressure is different. This pressure rises high during exercise, but as soon as exercise ceases it falls abruptly, almost to or even occasionally below its original level ; it starts to rise again almost at once to reach a fresh culmination about $\frac{3}{4}$ to 1 minute after the end of exercise, and from this culmination (about 160 mm. Hg) it falls back gradually and finally to its original level with the pulse. The first fall of pressure is due to the filling of a potential reservoir in the veins, when the subject relaxes.

Try to detect and plot the rising pressure at the end of exercise.[1] It requires quick and accurate observation. The blood pressure instrument should be so arranged that a pressure equal to that prevailing before exercise begins may be thrown into the cuff at the instant exercise ends, by opening a clip on a side tube leading to a pressure reservoir, the rise of blood pressure being subsequently followed with the hand bulb; the readings are called out and these and their stop watch times recorded by a second observer; the readings should come at about 10 second intervals.

If smooth curves can be obtained, superimpose several such curves taken after suitable periods of rest, and after exercises involving 20, 30, 40 and perhaps 60 lifts, and subsequently compare them.

Application

The exercises here described are those commonly used to gauge circulatory tolerance of exercise in patients. It is important therefore that the normal reactions should be known. Accurate standardisation is impracticable, because individual variation is considerable, and because the amount of energy expended is not precisely related to the amount of external work done; but definitely abnormal reactions are not difficult to recognise.

Another application concerns the fall of blood pressure which occurs at the end of exercise. This is so exaggerated in some patients that blood supply to the brain is affected to the extent of producing momentary dizziness or very transient loss of consciousness.

5d. *Heart sounds and impulse after prolonged exercise.* The normal heart sounds are usually two to each cycle; these are the 1st and 2nd sounds, which are paired together and mark the beginning and end of systole; they resemble the noise

[1] *Heart*, vol. 6, 269.

made by tapping lightly on a table with a finger. The two sounds are clearly struck and short and may be heard both at the impulse of the heart and also in the region of the 2nd costal cartilages near the sternum (the base).

The usual heart impulse is found confined to the 5th space, 8 to 10 cm. from the middle line.

These are the natural signs presented by the heart beating under resting conditions ; but when the action of the heart is augmented, they are apt to change. If a number of young subjects exercise, running continuously for 10 minutes or doing an equivalent amount of strenuous work in a gymnasium, the minute volume of the heart is increased and its rate is increased for a period sufficiently long to allow the changes to be seen.

After such exercise the subject should lie down in a horizontal light, or stand under an overhead light (a lighting which throws shadows into the rib spaces), and the visible cardiac impulse should be determined as quickly as possible and noted; not infrequently it will be found to have extended into spaces neighbouring the 5th. Further, while the heart's action is augmented, the heart sounds may be accompanied by distinct rushing noises (murmurs), either at the impulse (or outside it) or more frequently at the base. It is natural that the passage of blood through the heart should be noisier when the flow is accelerated.

Application

These same changes in impulse and heart sounds are apt to occur in any pathological condition in which the heart's action is augmented, as in fever or exophthalmic goitre ; unless the fact is realised, the changes will be interpreted as signifying disease of the heart.

6. VENEPUNCTURE

Use a sharp S.S. needle, 1 mm. or larger in diameter. Syringe and needle should be boiled for 15 minutes ; fit the needle snugly to the syringe with its bevel on the side opposite to that bearing the c.c. markings. The subject should lie supine and should not watch the procedure. His arm and hand should be warm ; if they are not, soak the hand for 5 minutes in hot water. Choose the largest vein in the right antecubital fossa ; the medial basilic is usually the largest and lies conveniently inclined. Wash over the skin to be punctured with ether. An assistant may pass a piece of soft rubber tubing around the upper arm to place a little tension on the veins ; it is to be relaxed the instant the vein is pierced ; but usually this assistance is unnecessary. Stretch the skin in the length of the vein with the left fingers and pierce the skin obliquely, with the bevel of the needle upward, in the line of the vein and relax the skin. Tilt the syringe a little and dimple the vein with the point of the needle. A slight forward thrust at once punctures the vein, when the syringe should be rotated until the c.c. markings come upward and the bevel of the needle is known to be downward. Draw what blood you want. Hold a pad of clean wool firmly on the puncture wound and withdraw the needle. Ask the subject to keep the elbow flexed, thus holding the pad in place, for 5 minutes. No dressing is required.

Application

Specimens of blood (a few c.c.) are frequently required clinically for estimation of urea, sugar, cholestrin, and other substances.

7. VENOUS PRESSURE

The pressure in most veins of the human body stands above atmospheric pressure. That is so in the case of all veins lying below the level of the base of the heart or, as it is more usual to express it, below the level of the 2nd costal cartilage; the latter expression is used because it applies both to the standing and supine positions. Veins above this level, like the external jugular vein in the standing subject at rest, are flattened almost to collapse.

7a. *Veins examined.* Examine the condition of the superficial veins in a warm subject with arms, neck, and feet bare, and standing leaning against a support and quite at rest. Note that the veins are undistended in the neck but are swollen and palpably under considerable tension on the dorsum of the foot. The differences in pressure within different veins is chiefly hydrostatic.

7b. *Veins emptied by movement.* Noting the fulness of veins on the dorsum of the feet, ask the subject to shift his weight from one foot to the other and back again; the movement will at once empty the veins but they will gradually fill again. They are emptied by pressure exerted by muscular movement on veins in the leg, the displaced blood being unable to return owing to the venous valves. The pressure of blood in the veins of the foot, though it rises high, very seldom rises to the full height of the hydrostatic column, however quiet the conscious subject is able to keep.

7c. *Bloodflow in veins.* Where there are prominent veins in the warm dependent arm, choose a long one, compress it below and wipe the blood upwards out of it. If there is a valve in the vein the column of blood will not fall back into

the vein, but will remain standing above the valve, the site of which will be seen readily. Press this blood column back against the valve, and it will render the latter more prominent and an idea of its adequacy will be obtained. Release the vein below and it will fill in its whole length from below upward ; this observation repeats one of the experiments Harvey used to demonstrate that blood moves in the veins towards the heart.

7d. *Pressure measured in arm.* Lift the arm and hand of the subject, keeping the elbow bent and the back of the hand upward, insisting that the subject keeps the arm quite passive and flaccid ; do it slowly, supporting the limb with two hands and watching the veins on the back of the hand. They will collapse about the time when they reach the level of the 2nd cartilage.

7e. *Pressure in cervical veins.* Let the subject lie supine on a couch, the head resting on a single pillow and note that, if an external jugular vein is visible, it becomes swollen for a short distance from the clavicle. Put a finger low down on the vein and it will become turgid in the whole of its superficial course. Remove the finger and the vein will collapse down to a certain level (zero line), this level is an excellent gauge of general venous pressure.

7f. *Pressure change with breathing.* Note that the zero level changes with respiration, falling with inspiration and returning with expiration. Press on the abdomen and the level will rise.

7g. *Tilt and its effects.* Lift the foot of the couch, lift the head of the couch, and the level will rise and fall relative to the neck, but will not change appreciably relative to the 2nd cartilage.

7h. *Veins and temperature.* The importance of having the limb warm in examining the veins in the limbs can be shown by soaking the two arms, one in water at 43° C. and the other at 20° C. ; the veins of the hand swell in the first and become indistinct in the second case. This is not due to differences of pressure within the veins, for the pressure can be made equal by obstructing the return in both (cuffs at 40 or 50 mm. Hg). It is due to differences in the tone of the vessel walls in response to local temperature.

7i. *Manometric reading.* A direct measure of venous pressure may be taken as follows : take a small (3 mm.) glass tube 12 inches long and bend the last inch of it at right angles, connect a 1 mm. hypodermic needle to this by a two-inch rubber tube fitted with a pinch clip. Sterilise this apparatus ; fill the needle, rubber tube, and an inch of the long glass arm with sterile 2% sodium citrate. Following a similar procedure to that already described (under 6) ask the subject to lie supine on the couch stripped to the waist, his warm arm lying by the side, and the elbow 6 inches below the level of the sternum ; while an assistant temporarily obstructs the returning veins, choose a fat short vein near the elbow and drive the needle into it. The assistant should at once relax pressure on the veins. Keep the long glass tube upright and release the clip ; the citrate, followed by a column of blood, will rise in the tube until the meniscus lies at the level of the sternum. Often the meniscus will be seen to oscillate with respiration and sometimes with the pulse.

The height of the meniscus, relative to the 2nd cartilage, is the measure of general venous pressure. The height of the column, from needle to meniscus, is the measure of the pressure at the point of puncture, and this is chiefly determined by the position of the arm.

To remove the needle, replace the clip, press a small piece of cotton wool over the needle and withdraw it, maintaining

pressure on the puncture for a few minutes. No dressing is required.

Application

Measurements of general venous pressure by the method of inspecting the cervical veins is in constant use in the care of cardiac affections,[1] in which the pressure is often increased, the zero level standing high in the neck ; changes of pressure in these cases form a chief index of progress.

Venous pressure is raised in a limb when the main vein becomes thrombosed, or when the venous valves become incompetent.

When the sympathetic nerve supply to a limb has been lost (by operation or otherwise) the veins become distended in this limb ; this difference is present with the veins kept at equal temperature and when the pressure inside the veins is brought to equality in this and the symmetrical limb.

8. X-RAY EXAMINATION OF CHEST

The following demonstrations are suited to a group of six students.

8a. *Screening the heart.* The standing subject is screened in the antero-posterior position to view the outline of the heart, its right border formed by superior cava and right auricle, its left by transverse aorta (the knob), the pulmonary artery, and the ventricle. The movements of the heart borders are small ; the left border shows the chief ; it is not usually feasible to time separately the movement of auricle and ventricle.

[1] Eyster, *Clin. Aspects of Venous Pressure*, New York, 1929; *B.M.J.*, 1930, i, 849.

8b. *Respiration.* The chief movement in the chest is by the domes of the diaphragm, rendered more prominent by deep breathing. Note the increased illumination of the lungs when a deep breath is taken and the increased exposure of the apical parts of the heart ; note also that the heart's apex tends to be tilted upwards in expiration.

8c. *Forced respiratory movement and heart size.* Now ask the subject, previously trained for the purpose, to take a deep breath, to close the glottis and expire forcibly, thus to exhibit the shrinkage of the heart with raised intrathoracic pressure. Then call for a full expiration, closure of the glottis and a forced inspiration, to illustrate expansion of the heart with lowered intrathoracic pressure. The difference in the size of the heart in the two circumstances is often remarkable.

8d. *Oesophagus.* Turn the subject into the right oblique position (right shoulder advanced) and demonstrate the clear zone of the mediastinum behind the heart. Ask him to take a mouthful of thick barium paste and to swallow this at a signal while standing in this oblique position. The movement of the paste through the mediastinum will be seen, as it passes down (a watery paste will travel too rapidly), and so will its hesitation as it reaches the cardiac sphincter of the stomach. Where the oesophagus is crossed by the aortic arch, the latter leaves a semicircular impression upon the oesophageal shadow.

9. ELECTROCARDIOGRAPHY [1]

9a. *Apparatus.* Set up the string galvanometer connected as shown in Fig. 2. The two ends of the string (*G*) are joined to form a circuit which is closed by the key (*K*1). The closure

[1] Further details and applications will be found in *The Mechanism and Graphic Registration of the Heart Beat,* London, 1925.

of this key keeps the string at rest and safeguards it from damage when it is out of use. When $K1$ is open the string circuit is thrown into the main circuit (M.C.). This circuit goes by leads to the patient and contains two high resistance wires ($W.W.$), each of which lies in a circuit of its own. The one belongs to the compensating circuit (C.C.) ; this consists of accumulator, key ($K3$), and resistance ($R3 = 19$ ohms) and slide wire ($W.W. = 1$ ohm). The wire $W.W.$ has an E.M.F.
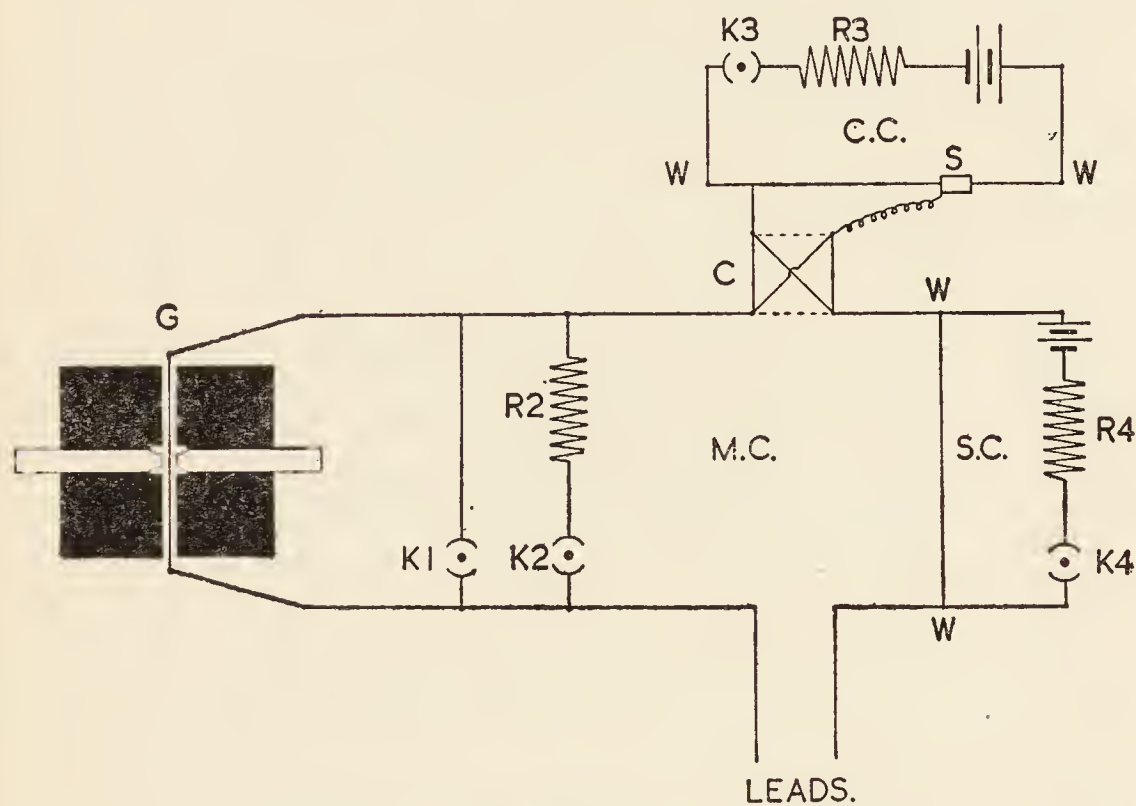
FIG. 2. Circuit for electrocardiography.

of 0·1 volt between its ends and any fraction of this may be thrown into the main circuit in either direction by using the slider S and commutator C. The other belongs to the standardising circuit (S.C.) ; this consists of battery, key ($K4$), resistance ($R4$) and wire $W.W.$, so arranged that with the closure of $K4$, an E.M.F. of 3 millivolts is thrown into the main circuit. A shunt, consisting of key ($K2$) resistance ($R2 =$ about 1 tenth resistance of the string), crosses the main circuit.

9b. *A standard electrocardiogram.* To take a human electrocardiogram, first connect up the subject to the main circuit through the leads, using the white metal electrodes provided and fastening them to the right forearm and left leg. The metal plates may be fastened over pads of salt solution ; but the special silicate jelly provided is more convenient. Most of the resistance, which the body contributes, is contributed by the horny layer of the skin. The jelly contains a little very fine grit which, when rubbed over the skin, greatly reduces skin resistance.

With the short circuiting key ($K1$) closed, activate the galvanometer. To throw the galvanometer into circuit with the patient open $K1$; but this is only to be done with $K2$ closed, so that a high proportion of any current passing in the circuit is shunted. Skin activity provides a constant E.M.F. of some magnitude (up to 0·05 volt) and this must be balanced at this stage from the compensating circuit. Then, and not till then, $K2$ may be opened. The galvanometer now experiences the full electromotive changes of the heart beat, as represented at the electrodes, and the string pulsates with the heart beat. Bring the string exactly to its zero line, and by slackening the string increase the sensitivity of the galvanometer until the base line is deflected through exactly 3 cm. on throwing in the standardising E.M.F. of 3 millivolts. This standard curve may then be photographed.

Comment. The standard curve from this lead (Fig. 3) consists of an auricular complex (*P* deflection) and a ventricular complex, itself consisting of initial deflections (*Q.R.S.* or *R.S.*) and of a final deflection (*T*). It provides useful measurements. The interval between the beginning of the auricular and ventricular complexes is a measure of conduction in the auriculo-ventricular junctional tissues and should not exceed 0·2 second in normal subjects. The initial

deflections measure the period during which the muscle of the ventricle is being activated and should not exceed 0·1 second ; the whole ventricular complex is a measure of systole and is about 0·3 second at ordinary heart rates ; the final deflection T indicates the retreat of the excitation wave from the ventricle.
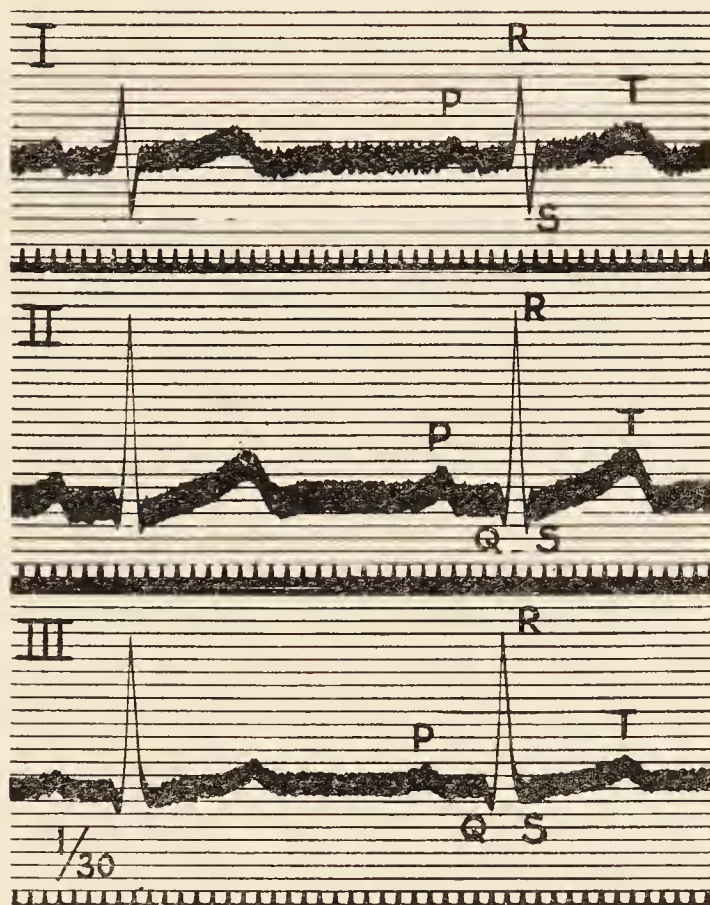
FIG. 3 (nat. size). Electrocardiograms from the three standard leads. Time marker in 1/30 second.

9c. *Potentials in three standard leads.* Standardising the curves as accurately as you can, take each of three curves from lead I (right arm to left arm), lead II (right arm to left leg), and lead III (left arm to left leg). Notice that in form and magnitude the deflections in these three leads is different. The E.C.G. not only represents potential changes in the heart, but it represents these in relation to the lead from which the curve is derived.

Now in passing from right arm you may go direct to the left leg (lead II) or indirectly by way of the left arm (lead I) and on to the leg (lead III). Thus, theoretically, the potentials of lead II must precisely equal the summated potentials of leads I and III. The accuracy of standard curves is proved if they fulfil this summation test. Inspection of properly standardised curves taken with the string galvanometer shows broadly that they are accurate. In your curves R of lead II should equal the sum of R of leads II and III; and the same should be true of the other deflections of your curves. The apparent summation is not always exact even in the most carefully taken curves; that is so because the summit of such a deflection as R does not represent precisely the same time instant in the heart cycle in the three leads. To show that the values of the three curves accurately summate, it would be necessary to bring them into quite accurate time relation with each other, for example by recording them simultaneously.

9d. *Respiratory changes.* Just as change of lead alters the E.C.G., so does change in the position of the heart, for both changes alter the relation of heart to lead. Using lead III, a conspicuous difference is often to be seen between curves taken during full inspiration and full expiration; the diaphragm in rising tilts the apex of the heart upwards, making the lie of the heart more horizontal.

9e. *E.C.G. and mechanical records.* Take an E.C.G. from lead II while allowing the shadow of a polygraph lever to fall on the same camera slit. In this way interesting time relations between E.C.G. and carotid, or venous curves may be studied. Remember, however, in calculating the intervals, that time is lost while the wave travels in the air of your rubber tubing.

Application

Electrocardiography is one of the chief methods of recognising disorders of the heart, including disorders of rhythm and disease of the muscle.

10. CAROTID SINUS PRESSURE [1]

The subject should lie supine, with head resting on a pillow. See that the neck muscles are fully relaxed and with the fingers of the left hand resting behind the neck, bring the thumb into the right carotid triangle just below the level of the angle of the jaw. Feel the beat of the carotid artery beneath the ball of the thumb, and press it directly and firmly backward against the bodies of the vertebrae to obliterate it. The compression should not usually be maintained for more than 2 or 3 seconds as it is uncomfortable to the subject. It usually results in quite distinct, exceptionally in profound, slowing of the heart beat. The effect is transient ; it can be obtained from either carotid vessel. It is due to slowing of the basal rhythm of the heart, exceptionally combined with some grade of heart block. The slowing can be appreciated by the compressing thumb, other observers can hold the radial pulses. A record can be taken from the brachial artery if it is desired. The two carotids should not be compressed simultaneously, for this is apt to interfere seriously with the cerebral circulation.

Application

Carotid sinus pressure is used in cases of paroxysmal tachycardia, in which it will sometimes bring a distressing paroxysm of rapid heart action to an end.

[1] The mechanism involved was discovered by Hering, *Die Karotissinusreflexe*, etc. Dresden, 1927.

11. GENERAL VASODILATATION AND SWEATING [1]

11a. *Temperature readings of skin.* Set up an apparatus for registering skin temperatures. The thermoelectric junctions are best made from enamelled wires (S.W.G.32) of eureka and copper. Scrape the enamel off the ends of the wires, lay them side by side and solder together the last $\frac{1}{2}$ cm. of each, cutting the soldered ends clean.

The basal arrangement (Fig. 4) is a constantan (eureka) wire forming such a junction with a copper wire at each of
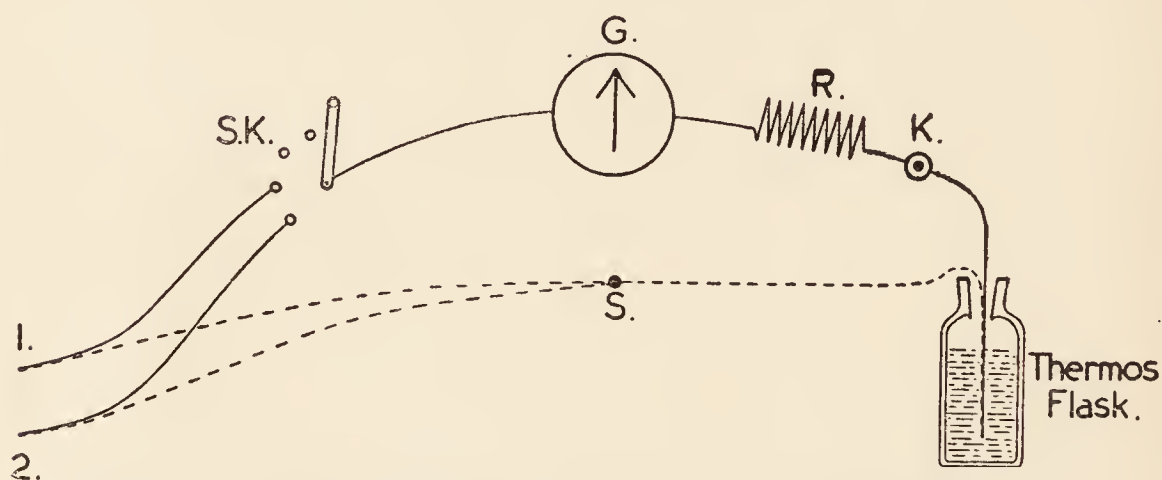
FIG. 4. Apparatus for thermoelectric estimation of temperature.

its two ends (a couple). One of the two junctions is immersed in water in a thermos flask at constant temperature (usually room temperature) and the other or testing junction is fixed to the skin. The constantan wire (broken lines in figure) is broken in its middle by a stud (*S*) composed of the same metal. The copper wires (continuous lines in figure) unite through a simple switchboard including key (*K*), resistance (*R*), mirror galvanometer (*G*). If more than one testing junction is to be used, all the constantan wires are brought

[1] See *Heart*, vol. 11, 178 ; vol. 15, 388 ; vol. 16, 33 and 115. *Clinical Science*, vol. 1, 213 ; vol. 3, 273.

back to the stud (*S*) and the copper wires separately to the studs of a switch key (*S.K.*). This switch key allows each testing junction to be connected with the galvanometer in turn. Thus readings of the galvanometer may be taken from any one of a number of junctions, of which two (1 and 2) are shown in the figure. The deflections resulting from differences in the temperature of the pair of junctions is calibrated by immersing the testing junction in well stirred water in a second thermos flask at known temperatures over the required range.

The testing junction should be fastened to the skin to be tested by a small piece of thin adhesive strapping; readings may then be taken from it repeatedly as required.

11b. *Vasodilatation and sweating by heating.* A simple means of procuring a full and lasting vasodilatation is by applying external heat and thus raising the temperature of the subject. The trunk may be covered by a cradle and exposed to radiant heat, or the subject may be placed in a hot bath; either is effective. But the most convenient way is to immerse two limbs in hot water. A hot drink will expedite the reaction. The subject should be suitably attired, so that while the body is protected from draught, the skin may be inspected, and so that discomfort may not subsequently result from the free sweating.

The subject is dressed in singlet and shorts, with large towel or blanket around the shoulders. To show the reactions well the extremities of the subject should be at a steady temperature and cool at the start, and this will usually require a room at a temperature about 18° C. Fasten terminal junctions to the tip of the middle finger, and to the back of the hand, and begin recording the temperatures of these points at two minute intervals to obtain base lines of sufficient constancy. If the hands are cool or cold at the beginning—and they should be—the finger tip will be

colder than the back of the hand. Now immerse the feet in a large bath of water, 12 inches deep, and keep them there and maintain the temperature of the bath at about 45° C. The reaction will come after a variable time, but is rarely delayed more than 12 minutes. The subject begins to feel a sense of general warmth, the temperature of the extremity of the arm begins to rise, the face often becomes flushed, and sweat beads begin to form.

Notice that the rise of temperature begins first at the end of the finger, the back of the hand follows suit after minutes of delay and its rise is less steep. Soon the finger tip is warmer than the hand, and continues to be warmer for a long time. These broad changes can be ascertained if necessary without instrumental readings.

The temperature of the fingers will rise till it lies at least 10° above room temperature (18°), and should reach 32° to 34° C.

Notice the distribution of sweating, how it affects especially the central parts of the face, forehead, lips and chin, where beads form, and how moistness of the skin occurs on the whole trunk and upper limbs, without particular involvement of the palms of the hands. The earliest increase of sweating on trunk or limb is detected by moving the back of one's own dry fingers lightly over the skin to be tested ; sweat notably increases the friction between the two skin surfaces.

11c. *Fingers as sluice gates.* If in this observation the terminal junctions are fastened to the dorsal surfaces of proximal phalanges of equal temperature and the circulation to the distal phalanx of one of these fingers is stopped by tying a rubber band around it, the rise of temperature at the base of this finger will be delayed and less in extent. That is so because the flood of blood which should run through arteriole-venule anastomoses in the finger tips and return through the veins of the finger is stopped.

The fingers are particularly important radiators of heat when heat is to be eliminated.

Application

Vasodilatation of a limb in response to heating the trunk or other limbs will not happen if the sympathetic nerve supply to the tested limb has been lost, neither will sweating. Both may be used to identify such loss, but the sweat reaction is the better because it accurately maps out the area of loss.

The vascular reaction is also modified where there is obstructive vascular disease. If the circulation to a limb is reduced solely by reason of spasm of its vessels, this spasm will usually be abolished by inducing loss of vasomotor tone, and a full reaction will be obtained, though perhaps after delay. But if there is obstructive disease the reaction will be absent or much reduced. The test is often used clinically for this differentiation and also to gauge the severity of obstructive disease.

12.   CALORIMETER AND BLOODFLOW

The rate of bloodflow to an extremity may be gauged broadly by observing the temperature of the limb under known conditions, and steep rises and falls of surface temperature will indicate changes in the rate of bloodflow. But this method is less sensitive and less accurate than is measuring heat elimination. For this purpose a calorimeter, adapted to the limb, is often used.

12a. *Calorimetric method.*[1]   The general arrangement is illustrated in Fig. 5. A thick walled earthenware pot is filled with small pieces of cork (*C*) packed closely around a central

[1] See *Heart,* vol. 3, 33 and 76 ; vol. 16, 115.
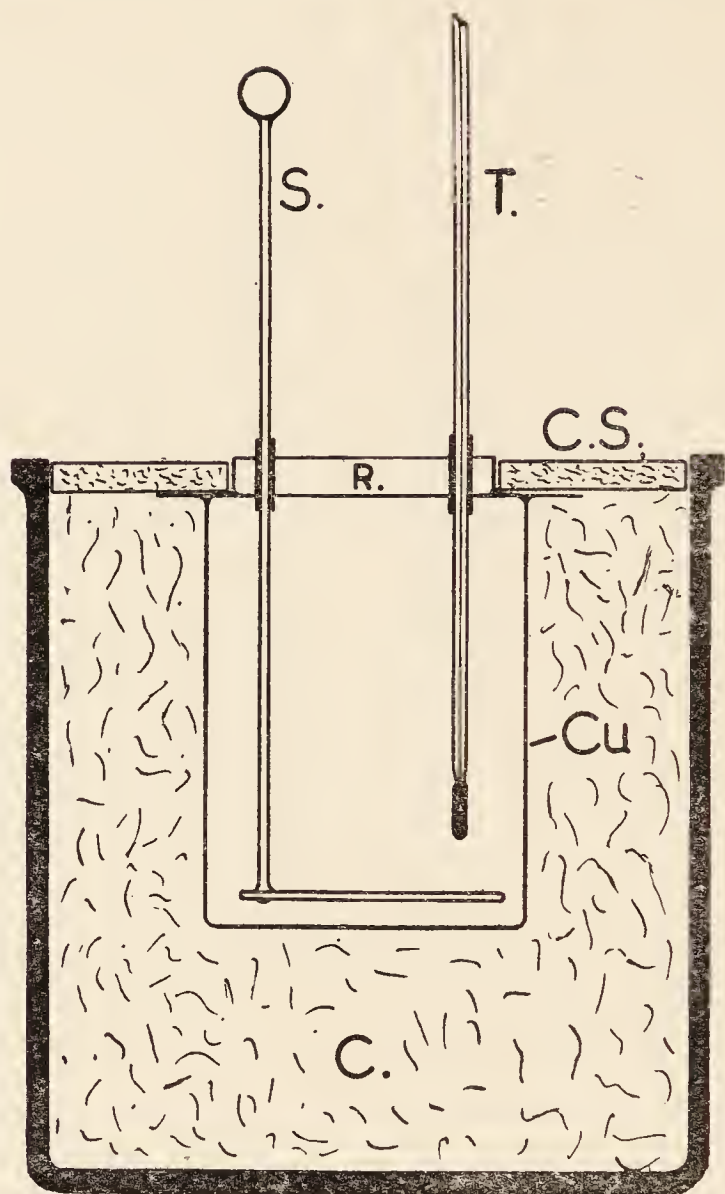
FIG. 5 (⅙ nat. size). Calorimeter arranged for the hand.

vessel of copper (*Cu*). The copper vessel is fitted at its mouth with a little platform to carry a close fitting and thick cork sheet (*C S*) closing the mouth of the outer vessel, and to carry a thick piece of spongy rubber (*R*) closing the mouth of the copper vessel. This rubber cap has a hole cut in it to admit the hand; it fits snugly on the platform and lightly around the subject's wrist. The apparatus is fitted with stirrer (*S*) and centigrade thermometer (*T*) on which hundredths of a degree can be read without difficulty.

Pour into the inner vessel a quantity of water previously ascertained to be adequate to fill the vessel to within a little

distance of the platform when the hand is in place. The hand from which heat elimination is to be measured should soak in a tank of water at about 30° C. for 10 or more minutes ; and the water should be taken from this tank to fill the copper vessel just before the hand is quickly moved from one to the other. As soon as the hand is snugly in place, stirring should start and continue, the temperature of the water being taken at minute intervals and charted.

Working in a room at a steady temperature of 20° to 22°, the hand will give up heat to the water and the temperature of the latter will gradually and steadily rise. The curve of this rising temperature will be influenced by any appreciable increase or decrease of bloodflow to the hand.

To obtain smooth curves, it is quite essential to work in a quiet room, in which there are no draughts or other changing external conditions, and the subject must be clad and in a comfortable reclining position, with body and mind quite relaxed. Without these precautions distinct fluctuations in bloodflow to the hand will occur and the curve will show corresponding irregularities, interesting in themselves.

12b. *Heat elimination and arrested flow.* While the temperature of the calorimeter is rising steadily, arrest the circulation to the limb by throwing pressure into a cuff already in place on the upper arm. The curve will cease to rise and will soon begin to decline, the bloodflow to the hand having ceased, and heat being now lost from the calorimeter.

12c. *Reflex slowing of bloodflow by cold.* In another observation, while the temperature curve is rising steadily, and with everything prepared beforehand, immerse the opposite hand in water at 15° C. This will bring an immediate decline in the rate at which the curve rises. These changes in heat elimination of the hand within the calorimeter reflect corresponding changes in bloodflow.

12d. *Change of body temperature and bloodflow.* The decreased heat elimination which comes at once as a response to immersion of the opposite limb in cold water is reflex ; it will be seen to occur even if the circulation to this limb has been stopped before it is cooled, and it is transient. A second fall of heat elimination will occur on releasing the circulation to the cooled hand, and this second fall will persist. It is not reflex, but due to the influence of colder blood returning in the veins upon the heat regulating centre. Warming the opposite hand, with its circulation arrested is without effect ; the vasodilatation which follows warming with circulation free is again a direct effect on the heat regulating centre.

Drinking 500 c.c. or more of water at 46° C. causes, after a few minutes delay, a sharp rise of heat elimination from the hand.

12e. *Measuring heat loss.* At the end of each observation, or series of observations, the hand should be removed, and the calorimeter closed by an intact lid of spongy rubber and, stirring being continued, the rate of cooling should be determined. The heat elimination from the hand in small calories from minute to minute can be calculated as follows : (Change of temperature of calorimeter in one minute + correction for cooling of calorimeter) × (water content + water equivalent of calorimeter) ; and, if it is desired, the curve may be plotted in this form.

13. PLETHYSMOGRAPH

13a. *Plethysmographic method.*[1] In using plethysmographs upon the limb, a chief difficulty is to obtain a flat preliminary base line. This is partly due to small changes in

[1] See *Heart*, vol. **1**, 87 ; vol. **12**, 73.

vasomotor tone that constantly occur in the conscious subject unless he can be reduced to a state of unusual physical and mental quietude. It is necessary to the observations that the room in which they are conducted should be quiet, warm and draught-free, and that the subject should be completely restful and as little interested in the observations as possible.

An adequately flat base line is very difficult to obtain with a plethysmograph holding the whole arm, owing to slight but unavoidable displacements of the limb in and out of the container.

Use therefore a plethysmograph in the form of a truncated cone (Fig. 6). It is applied to the middle of the forearm,
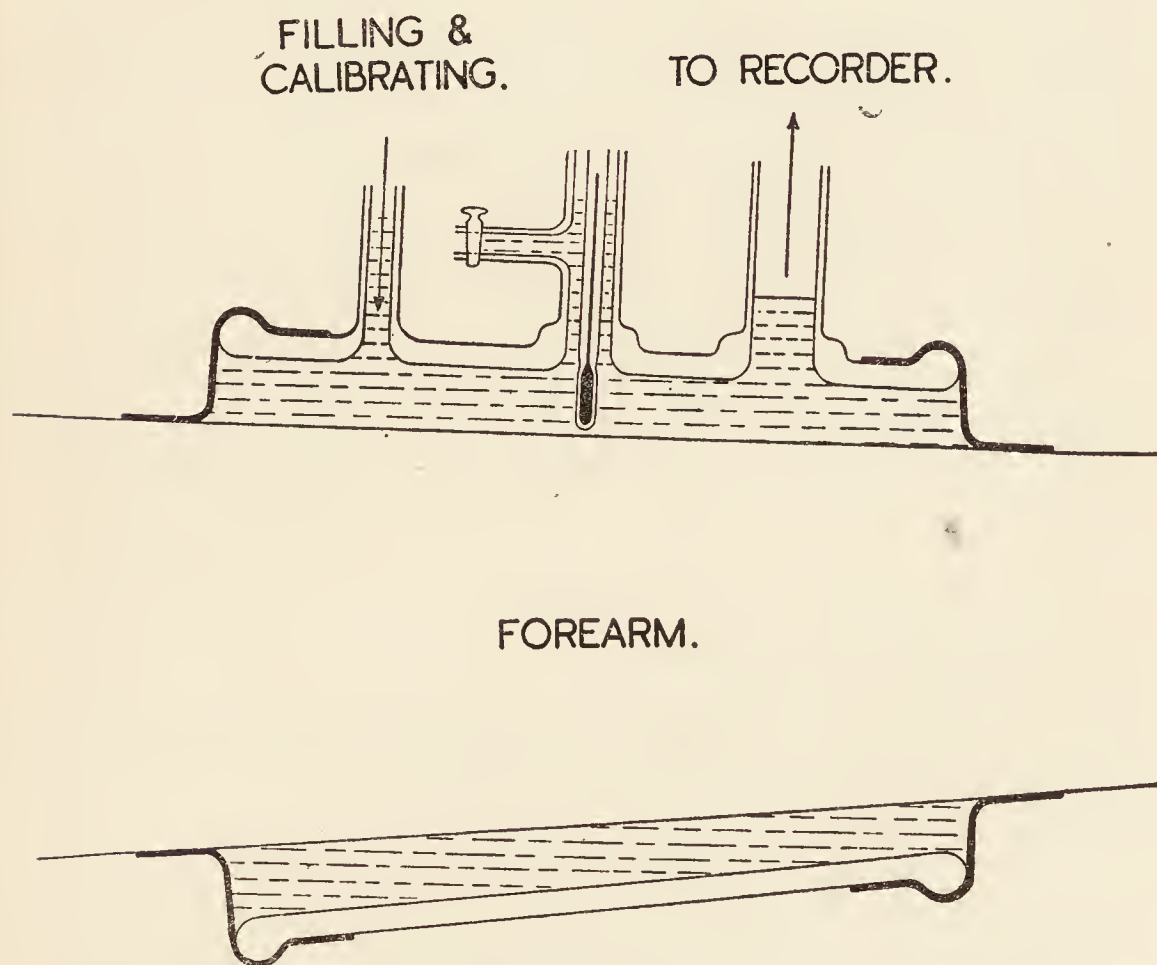
FIG. 6 ($\frac{2}{5}$ nat. size). Plethysmograph to take the forearm.

the wrist and elbow being unenclosed. The two ends are closed by fitting suitable lengths of tyre tubing over each and inserting the arm through these. The rubber tubes are cut

of such length that only a little of each rests flat against the skin, enough to render the apparatus air tight without compressing the arm. The wrist and elbow are rested upon and firmly wedged by sand bags, to support and hold the limb, the whole being sunk below the surface of a narrow bath of water maintained at a controlled temperature. The plethysmograph should be fitted with a thermometer, an inlet tube for filling it with water and for calibrating, and with a wide and vertical outlet tube in which the water is allowed to form a surface, the movements of which are transmitted pneumatically to a volume recorder (a recorder giving about 1 cm. excursion to 5 c.c. volume change is suitable). The plethysmograph and bath should be filled with water maintained at a constant temperature, ordinarily about 33°. When the subject has rested and the temperatures of bath and arm are in equilibrium, the record obtained should be flat except for the small excursions of pulse beat and respiration. With the volume curve recording proceed to test the apparatus.

Testing. Place a pneumatic cuff snugly around the upper arm as far from the elbow as space will permit and throw pressure on to the veins gradually. If more than 10 or 15 mm. Hg pressure can be imposed without the volume of the curve rising, the rubber cuff closing the top of the plethysmograph is itself exerting too much pressure on the returning veins and it should be cut shorter.

Throw a pressure of 70 mm. Hg abruptly into the cuff. The jerk that results should not displace the record by more than 2 mm.

13b. *Reactive hyperaemia curves.* Take off the cuff and bring your fingers behind and around the upper arm ; find the brachial artery and with one or two fingers gently but firmly compress it, noting the loss of pulse beat from the volume curve and the fall in the volume of the limb. Maintain the pressure for 10, 20, and 40 seconds in successive

tracings, noting the swelling of the limb in the phase of reactive hyperaemia at the release. This increase of volume beyond its original value is the greater, the longer the preceding occlusion.

Alternatively, occlusion of the arteries may be undertaken by throwing an obliterating pressure into the cuff on the upper arm, for successive periods of 1, 2, and 4 minutes, obtaining the volume curve of the release in each case.

13c. *Bloodflow curves.* Throw a pressure of 60 mm. Hg into a cuff on the upper arm. At once the curve will begin to rise on a slow incline. This increase of volume is due to retention of blood in the veins. Its first inclination to the horizontal is a measure of the rate at which blood is entering the limb at the instant the pressure on the veins is raised, for this pressure while at first not interfering with inflow will prevent all outflow from the arm. An absolute measure can be obtained by calibrating the machine ; it is however to be remembered that blood is returning to the plethysmograph from the hand as well as from the arm, and that the measure is not simply of bloodflow to the part of the arm in the plethysmograph.

13d. *Bloodflow and local temperature.* If desired, comparisons may be made of the bloodflow into the arm when this arm is at temperatures of 25°, 35°, or 40° ; the flows will be found to be very different. Or a consecutive series may be taken at minute intervals following a 10-minute arrest of bloodflow to the limb, to show the gradual decline from the increased flow occurring at the release.

13e. *Reflex effects of cold.* The effect on the volume curve of plunging the opposite arm into cold water may be tested. It gives an abrupt reflex decline of pulse and total volume.

Application

Calorimetry and plethysmography have clinical applications, for example, in cases of peripheral arterial disease and in detecting interruptions of vasomotor nerve channels.

14. USE AND BLOODFLOW

The supply of blood to a given limb is associated with its use ; in disuse the bloodflow declines.

In a cool room (16° to 18°), use one hand for work, such as notetaking, moving books and so forth, while the other hand is kept still and hanging by the side. Within a half-hour the hand that works will be found to be several degrees warmer than the idle hand.

If a hand is laid palm downwards on a table and voluntary movement of the hypothenar muscles are maintained continuously in a cool room, the ulnar side of the hand becomes hotter relative to the radial by several degrees within 10 minutes. The increased temperature is largely due to increased bloodflow to the muscles used.

15. CAPILLARY PULSATION

Most of the vessels concerned in colouring the skin belong to the superficial subpapillary venule plexuses. They have the structure of capillaries, but in the strictly anatomical sense the capillaries are confined to the papillae. The venules contribute chiefly to so-called " capillary " pulsation, though all the minute vessels are involved ; the pulsation is known to be transmitted from the arteries to the venules through the capillaries.[1]

[1] See *Heart*, vol. **11**, 151.

15a. *Capillary pulse displayed.* Lay a hand in water as hot as can be borne for three minutes. The temperature lies almost always within 1° of 46° C. Dry the hand quickly and examine it by pressing a glass slide upon the pads of the finger tips just hard enough to almost blanch them. Capillary pulsation is seen as an ebb and flow of colour to the blanched area, especially at its edge, at each pulse beat. The pulsation is not always easy to appreciate ; it is easiest to see with the skin at 18 or 24 inches from the eyes. In some subjects it is conspicuous. In others experience may be required to detect it. It can be found in any part of the palmar skin, and also in the nail bed, after heating, and is present in all healthy young subjects.

It is to be found in greater or lesser degree as a spontaneous phenomenon in the mucous membrane of the lower lip, and in the lobes of the ears when these are hot, as after rubbing, in many normal young people. It declines with age and is comparatively rare after 60 years, even in the heated hand.

15b. *Amyl nitrite.* A capsule of amyl nitrite inhaled gives a vivid blush of the face. Capillary pulsation is distinct in this flushed skin.

Comment. This capillary pulsation is due to vasodilatation, to an open condition of arterioles in the locality ; this may be shown as follows :

15c. *Local heating.* Extend the fingers, supinate the hand, flex the wrist and, keeping the finger tips in the air, immerse the rest of the hand and forearm back downwards in a bath at 45° C. for 3 minutes. Although this procedure will heat and dilate the arteries of the hand and of the proximal parts of the fingers, it will not produce capillary pulsation at the finger tips. Heat similarly no more than the pad of a single finger for the same period ; and pulsation will be found in the part heated.

The area which it is necessary to heat is very small ; thus, when a beam of unfiltered light is concentrated on a few square millimetres of skin, concentrated just enough to produce sting, the skin throbs perceptibly to the subject and capillary pulsation appears in this small area.

15d. *Local inflammation.* Capillary pulsation will usually be seen in the reddened skin of any quite recent inflammatory lesion of the skin, for example around a fresh razor cut or scratch or in a newly formed acne papule, or in a wheal raised experimentally.

Comment. Capillary pulsation depends upon dilatation of the small arterioles of the skin itself.

Application

Capillary pulsation occurs in many pathological conditions ; these all have one factor in common, namely, vasodilatation. Such conditions are aortic regurgitation, thyrotoxicosis, fever, and injuries to the sympathetic nerve supply to the skin. The capillary pulse is never seen in skin that is cold.

The pulsation is used, firstly, as an indication of vasodilatation and, secondly, to test the capacity of vessels to dilate. Thus, if fingers or toes are persistently blue and cold in ordinary surroundings it becomes important to determine whether this is due to increased vascular tone or to clotting or other obstruction in the vessels. Heating the part will help to determine this, because in spasmodic conditions the vessels will then relax and capillary pulsation will appear at the tips of the digits, showing clearly that the channels are now open. If the pulsation fails in these circumstances it may be concluded that obstruction is present.

16. CAPILLARY MICROSCOPE

16a. *Method.* To view the human capillaries requires the right apparatus and some patience.[1]

The best apparatus is a binocular dissecting microscope, moving freely in a horizontal arc and having a coarse and fine vertical adjustment ; but much can be seen on the stage of an ordinary microscope. The magnification should be from 10 diameters to 50, according to the amount of detail required. An essential adjunct is a strong beam of light, filtered through a dark blue or green screen ; and a beam that can be focussed on any desired point ; the red rays of the concentrated light would burn the skin, a green or blue light helps to bring the vessels into view.

The most convenient place to view the vessels is in skin at the base of the middle or ring finger nail. The horny layer of skin should be allowed to grow forward over the nail for a week or longer, for this brings the loops more at right angles to the line of vision.

Decide upon the stand on which the finger is to be placed for examination, the arm and hand being in a quite un-strained position, and arrange a bed of plastocene that will gently but securely hold the finger. It is possible but not so easy to examine one's own finger. With a razor blade shave away skin at the base of the nail, cutting parallel to the surface and taking off most of the horny layer without draw-ing blood. Fix the finger on its stand and place a drop of cedar wood oil or liquid paraffin on the surface to be exam-ined. The microscope should be brought to bear almost at right angles, and the beam of light at about 45°. The first essential is to obtain a view free of light reflex, and this the oil greatly helps. The capillary loops at the base of the nail will be brought to view readily by this means under a low

[1] See *Amer. J. Physiol.*, vol. 29, 335 ; *Heart*, vol. 11, 171.

power, and a higher power may be substituted. Do not be disappointed if the outlines of the capillaries at first seem misty ; it is surprising how much improvement of view minor adjustments, better lighting, and especially very close observation will bring.

16b. *Congestion and its effects.* Having obtained a view of the capillary loops, and these with a few of the minute venules into which they lead is as much as is usually visible, impede the return of bloodflow through the arm by congesting the veins. As soon as the skin becomes engorged the capillaries and venules will swell and become more prominent. Moreover, because the obstruction slows the flow of blood in the vessels, this flow will become much more distinct. When really slow, the individual blood cells can often be seen as they pass, white cells being recognisable from red by their higher refraction. The stream of blood is most difficult to see when it is very rapid, the corpuscles become blurred, as do the spokes of a rapidly revolving wheel. See the flow when it is slowed down, and the flow can be increased at will until it is full again.

16c. *Arterial occlusion and its effects.* Stop the flow to the arm and note how long it takes for the blood to come to a first standstill in the capillaries ; often it ebbs and flows before coming finally to rest.

16d. *Blistered skin.* Much clearer views of the vessels can be obtained if the horny layers of the skin are first removed by a blister, though this brings the vessels into a state of full inflammatory vasodilatation, and a little surface coagulum must be wiped away from time to time. In some such preparations the vessels stand out as clearly as those in the frog's web.

A very clear view can be obtained of the flow in the vessels of the sclerotic ; in this case, however, it is necessary that the subject should be able to fix his eyes very steadily on one object for appreciable periods.

17. SKIN COLOUR AND ITS RELATION TO TEMPERATURE AND BLOODFLOW [1]

Observations on skin colour should be made in a good natural diffuse light rather than by artificial light.

The vessels of the skin mainly responsible for its vascular coloration are the minute venule plexuses lying just beneath the epidermis. In considering the vascular coloration of skin a distinction should always be made between depth of colour and tint. The first depends on the total quantity of blood pigment in the vessels (comprising richness of the blood and size of vessel), the second depends on the relative quantity of oxyhaemoglobin and reduced haemoglobin.

A deep colour of the skin does not mean increased blood-flow to it ; the contrary relationship is much more usual. When parts of the skin are persistently deep coloured, they are in general found to be cooler than neighbouring pale skin ; the reddened parts of a child's or young person's face are the colder parts. When bloodflow continues to be rapid through skin, the skin becomes pale. Presumably this happens because the rapid flow washes away natural vaso-dilator substances from the tissue spaces and consequently the tone of the minute venules increases. Highly coloured hands are usually cold, and pale hands warm. It is true that

[1] Further information relating to the matter of this and sections 18 and 19, with original references, may be obtained from the author's *Blood Vessels of the Human Skin and their Responses*, London, 1927.

blushing brings a flood of colour to the face, but this is temporary, and it gives place as do all acute flushes to subsequent pallor. The vessels of skin are narrowest when the skin in virtue of blood brought to it is a few degrees below blood temperatures; they are dilated by the application of excessive cold or excessive heat.

The tint of the blood in the vessels is controlled in normal subjects by (i) the rate at which blood flows through the vessels, for the faster the flow the less oxygen is lost by a given quantity of blood to the tissues and by (ii) the temperature of the tissues, oxygen being more readily dissociated from haemoglobin and the tissues using more oxygen at the higher temperatures. Very little oxygen is dissociated below 15° C.

17a. *Temperature affecting oxygen usage.* Prepare two baths for the hands, one at 20° C. and the other at 42° C. Place pneumatic cuffs on the upper arms of the subject, abruptly stop the bloodflow to the arms by throwing pressure (180 to 200 mm. Hg) into the cuffs with the arms dependent so that plenty of blood is caught up in the skin. Now immerse the hands in the baths. The hand in the 42° bath will become fully cyanosed within about 4 minutes; only a little change will occur in the tint of that in the 20° bath during this time because the tissues can take up little of the oxygen from the blood.

17b. *Bloodflow and tint.* To show change of tint through increase of bloodflow, first congest a warm but unheated limb by throwing a cuff pressure of 60 or 70 mm. on to the upper arm. When the arm has become purple in tint, immerse the hand in a bath of water at 42° and keep the hand so still that the water line does not change. Take the hand out in a few minutes and you will find the hand bright red to the water line; although this part of the skin uses more oxygen because

of its higher temperature, yet increased bloodflow more than compensates by decreasing the amount of oxygen lost from each unit of blood passing.

Note that the hand to which the bloodflow is stopped or to which bloodflow is much impaired will not long tolerate immersion in water at 45°, for the skin is not bathed by a free flow of blood coming to it at a lower temperature. Patients with defective bloodflow to the limbs should never plunge these into hot water.

17c. *Local temperature on tint and size of vessels.* Use hands that have not recently been heated, and for 5 minutes immerse one in a bath at 35° and the other at 20° ; the former will remain pale and pink, the latter will become bluer (cyanotic). Now immerse one hand in water at 45° C. and the other at 10° C., and compare them after 5 minutes ; both the hands will present a very deep blood coloration and both will be bright red ; the minute vessels in both are very dilated ; in one the bloodflow is very rapid and in the other oxygen usage is negligible.

Notice that the veins in the hot hand are large and in the cold hand small. You will often be able to detect that the radial pulse is larger in the warm hand ; and in this hand if you clasp a finger you will feel the arterial throb in it, and in its pulp you will find capillary pulsation (see 15).

Put the cold hand back in its bath at 10° C. and stop the circulation to it. The cold penetrating deeply will be painful, but let it stay there, noting that there is little or no change in its tint, although the circulation has been stopped, after 10 minutes.

Comment. Cyanosis appears in normal skin when the skin temperature ranges from about 15° or 20° to 25° C., provided that the subject is at rest in a cool room, that is to say if the conditions are such as to give a moderate vasomotor tone.

All local changes in the vessels to which attention is here drawn result from the direct effects of temperature. Any indirect or reflex effects occur equally in the two hands; and they are relatively too inconspicuous to influence materially the direct effects here described.

There is evidence that the great dilatation of the minute vessels, both to excessive cold and excessive heat here described, is the result of tissue injury and due to an unusual release of vasodilator substances within the skin.

Application

If the simpler facts governing the relation of skin colour to temperature and to bloodflow are not understood, many changes of skin colour seen in pathological conditions will be interpreted erroneously. Cyanosis may be due to slow movement of the blood through the minute vessels or it may be due to deficient aeration of the blood as it leaves the heart.

If cyanosis is due to abnormality of blood pigment as it leaves the heart (high content of reduced haemoglobin, sulph- or meth-haemoglobin) nothing that you can do to increase the bloodflow locally will abolish the cyanosis, even though you produce signs of vasodilatation (capillary pulse, pulsation of digital arteries, etc.). If cyanosis is due to high tone of the arterioles in the skin in which it is observed, heating that skin or rubbing it will abolish the cyanosis; but heating skin will not reduce cyanosis, may indeed increase it, if it is due to slow flow of blood through the minute vessels owing to obstructive disease in the arteries.

The importance of comparing pulses and veins and colour in symmetrical limbs at equal and not at different temperatures will be apparent.

18.   CAPILLARY CONTRACTION

The minute vessels of the skin, the anatomical capillaries and minute venule plexuses that together constitute the physiological capillary bed, are all capable of active contraction. That these minute vessels, which give skin its vascular colour, can so contract can be proved very easily.

18a. *White reaction.*   Take a piece of wood, of the dimensions of a flat ruler, and sandpaper the end of it to round off the corners a little and make all smooth. Choose several subjects in whom the skin of the arms is warm, and not pale but distinctly coloured by blood, and proceed. Stroke the skin of the front of the forearm with the flat end of the ruler, using a steady pressure that is (or is just a little more than) adequate to blanch the skin as it travels. Make two strokes horizontally and an inch apart and watch the result.

Almost as soon as the ruler passes, the skin that is thus blanched returns to its normal colour, so that the area stroked can no longer be identified. But in about 20 seconds on one of the arms, on all if the subjects are fortunately chosen, blanching will reappear. Often, and especially in young subjects, the band of reappearing whiteness is conspicuous, and the whole area of the stroke blanches and remains blanched for 3 to 5 minutes. This is the " white reaction " and it is due to active contraction of the minute vessels in the skin displaying it. The white reaction can be obtained in most subjects, but is not always so conspicuous as to be at once convincing.

Comment.   It will be obvious that in the white reaction the minute vessels have decreased in size ; it becomes a question of whether this change is passive and brought about by contraction of arterioles, or active and due to contraction of the minute vessels themselves.

18b. *Capillary contraction proved.* Choose a subject who shows the white reaction well. Place a pneumatic cuff on the upper arm and throw a pressure of 200 mm. Hg abruptly into the cuff with the arm dependent. Wait one minute, while the pressure in arteries and veins is equalising, which it is known to do in this interval. Now stroke both forearms, and the white reaction will appear on both after the same time interval and will last for the same time on both. While it is there press a finger on the skin of the arm to which there is no bloodflow ; press just hard enough to blanch the skin and, on removing the finger, the blood will at once return.

Comment. The appearance of the white reaction when the pressure in arteries and veins has been equalised cannot be explained as the result of contraction of the arterioles. It must be due to active contraction of the vessels that give colour to the skin and these are the physiological capillaries. And in the arm to which bloodflow has been stopped note the contrast between the behaviour of the skin that has been blanched in response to finger pressure and that which after delay has followed the stroke with the ruler ; blood flows back into the first but not into the second ; the reason for the difference is that the displacement of blood in the first is passive, while in the second it is active, and due to firm and continued contraction of the capillary walls.

18c. *White stroke reaction a tension effect.* If a conspicuous white reaction is obtained, place two fingers an inch apart on the same skin and put tension on the intervening skin and release it. Presently this intervening skin will show a white reaction ; the stroke similarly stimulates by putting tension on the skin.

18d. *White reaction of adrenaline.* If a conspicuous " white reaction " has not been obtained, it can usually be emphasised by stroking an arm fading after the flush which

diffuses through the skin after a stopped bloodflow has been released. But if there is any real difficulty in displaying it, and there should not be when there is a choice of subject, it can always be shown by using adrenaline. Place 3 separate drops of a 1 in 1000 solution on the skin of the forearm and lightly prick the skin through each of these. A small blanched area will appear around each prick in 15 to 60 seconds. This reaction is given with equal intensity by skin previously deprived of its circulation ; a fact which proves that adrenaline is capable of producing active contraction of the minute vessels. Pituitary extract acts similarly. In using adrenaline hydrochloride solution, it is really sounder to buffer the solution immediately before using it ; the commercial solution is rather strongly acid, though the acidity does not interfere with the success of this test.

18e. *Force of capillary contraction.* When you have produced white reactions on the skin of a forearm by stroking the arm or by pricking in adrenaline, proceed to show how resistant this tonic capillary contraction is to internal pressure. This is done by studying the effect of raising venous pressure. Throw 30, 40, 50 mm. Hg pressure on to the veins ; these pressure rises will develop fully in the minute vessels within a short time, but will not cause the white reaction to disappear. Often the contraction will resist an internal distending pressure of as much as 80 or 90 mm. Hg.

Comment. It is not a question of the minute vessels of the blanched area being protected against the entrance of blood by contracted arterioles, for the former vessels form part of a freely communicating plexus which is fully distended under pressure right up to the blanched skin.

18f. *Pressure resisted and overcome.* The pressure that can be resisted is greater than the pressure that can be overcome when the vessels are already open. Prick adrena-

line into the dorsal skin of the foot of a subject standing quite still, and little reaction will be seen ; but if after a minute or two the subject takes a few steps, the blanched area will at once appear and will not disappear if he resumes his stationary position.   The reason is that the steps at once lower pressure in the veins, the capillaries are then able to constrict and once constricted the tension in their walls keeps them so.

18g. *Contraction of capillaries under microscope.*   The capillary microscope (see 16) may be used to watch the contraction of anatomical capillary and venule in skin deprived of its circulation and responding to adrenaline pricked in.

19.   TRIPLE RESPONSE

The triple response consists of three independent reactions and is the typical response of skin vessels in any simple acute inflammation.   The three parts of the response are : 1, local redness ; 2, flare ; and 3, wheal.   These three parts are not equally well displayed to all forms of stimulation.   The stimulus to produce flare and wheal must be stronger than for the local redness.

19a. *Needle scratch and flare.*   Grip the back of the forearm, thus tightening the skin of the front of the forearm a little.   Use a fine clean needle and stroke the forearm with the point hard enough distinctly to ruffle the horny layer of the skin but without drawing blood.   Release the arm.   In about $\frac{1}{2}$ to 1 minute you will notice that the skin for 1 or 2 cm. on each side of the scratch exhibits a scarlet flare.   This varies in intensity in different skins ; in some it is just distinct, in others it is vivid.   It is diffuse and often soon

seems rather patchy, especially at its margins, where it may be displaced subsequently by a border of unusual pallor, or be broken up by small areas of pallor.

In 3 to 5 minutes you will find along the line of the scratch a minute but distinctly raised wheal; stretch the skin and the wheal will show up more plainly; the fluid which has exuded into the skin increases the tension and this skin therefore pales first when stretched.

19b. *Blunt point and local red reaction.* The local redness is usually concealed by the flare when a needle point is used, but if a blunt round-ended rod (about 4 mm. diam.) is used instead, and the stretched skin is firmly stroked, the local red reaction invariably appears as a narrow red band (it comes in 3 to 15 seconds), while the flare will only appear faintly, and the wheal scarcely at all, unless the skin is a susceptible one or the stroke is very firm, or repeated several times along the same line.

19c. *Local reaction displayed.* The local redness is best displayed, and both to scratch and stroke, in the following way. Place a pneumatic cuff on the upper arm, and congest the veins by throwing 30 mm. Hg pressure into the cuff. Now abruptly raise the pressure to 200 mm. Hg to stop all bloodflow to the forearm. Scratch and stroke the skin (as in 19a and 19b). Within 2 or 3 minutes a purple band will appear in the skin along the line of the stroke, and a thinner purple line along the scratch. But no flare will come; and it is because there is no flare to confuse the margins of the local redness that the latter stands out so clearly. Note how precisely the band marks out the margin of the skin that has been stroked (the precise margin can be marked directly after the stroke).

Comment. The local red reaction is due to an active dilatation of the minute vessels; it is not due to passive

dilatation resulting from opening up of arterioles, for such a passive effect cannot happen when the circulation to the skin is at a standstill.

The flare on the other hand is due to arteriolar dilatation. Where in response to a heavy stroke both appear distinctly, the colour of the flare is seen to be of a brighter redness than that of the reaction on the line of the stroke. It is because it is purely arteriolar that a flare never appears on skin to which bloodflow has ceased. Because it brings a great increase of bloodflow to the skin the flare is often subsequently replaced by pallor (see 17).

19d. *Congestion and red reaction.* Throw a pressure of 60 or 70 mm. Hg into the cuff on the upper arm, and scratch the forearm skin when, after a few minutes, the congested arm has become purple. The flare will now appear as a bright red reaction on this purple background. Its redness clearly displays the increased flow of blood in the affected skin. Sometimes its increased warmth can be detected by touch.

19e. *Histamine.* Place on the skin a tiny drop of 1 in 3000 histamine (calculated as base = 1 in 1000 of the phosphate). Prick the skin through it with a sharp needle, but not hard enough to draw blood. Mop off the drop with filter paper. Within a half minute a flare (usually to the accompaniment of itching) will have appeared around the prick; it is 2, 3, or 4 cm. in diameter; in 3 to 5 minutes, a small round wheal will appear centrally. This flare and wheal are the counterparts of those seen in response to a scratch.

To display the local reaction, repeat 19c using histamine pricked in as the stimulus. Wherever it is pricked in a purple spot will appear and will extend a little. But no flare will be seen.

To display the flare to advantage, repeat 19d using histamine.

19f. *Nerves and flare.* The independence of the local red reaction and of the flare will already be obvious. They are due to independent mechanisms. The local reaction is due to the direct action of a released histamine-like substance on the minute vessels of the skin. The flare is due to the action of this released substance on vasodilator nerves in the skin. The flare has been shown to occur on skin to which the sympathetic nerves have been allowed to degenerate and on skin to which cutaneous nerves have been freshly cut, but never on skin in which the latter nerves have had time to degenerate (namely, 6 to 10 days after section). The flare comes through an axon reflex in nerve fibres belonging to the posterior root system. This demonstration is unsuitable for class work, but the dependence of the flare upon a local nerve mechanism can be shown quite easily by local anaesthetisation. Use a hypodermic syringe fitted with a short and very fine S.S. needle (0·3 mm. diam.). Keeping the needle almost in the same plane as the skin, drive it in very superficially and just far enough to close the oblique mouth of the needle. Inject 0·02 to 0·04 c.c. of 2% procaine hydrochloride (novocaine) solution. This should form a little wheal on the skin. Prick histamine into this wheal, or prick histamine into the skin and inject the same spot with procaine within a $\frac{1}{2}$ minute, and no flare will appear.

19g. *Refractoriness.* To show that the wheal is independent of the local red reaction use histamine. Stop the blood-flow to the arm, prick histamine (1 in 3000) into 2 or 3 points in line on the forearm, smear a very thin layer of vaseline over the pricks, and lower the forearm into water at 43°. Keep it thus for 5 minutes. While the circulation is stopped the local reaction will be seen, but there will be no whealing. Release the circulation after withdrawing and drying the arm ; still no wheal will form, and you can usually show that repuncturing precisely the same points with histamine will

still fail to give wheals, though they can be raised on neighbouring skin. The skin has become "refractory" to histamine. But more important at the moment is the demonstration that the vessels may dilate locally without a wheal following.

Wheals are due to a grossly increased permeability of the vessel wall, a change independent of dilatation of the vessel. Wheals however, unlike the flare, are not dependent upon the presence of cutaneous nerves.

Comment. These are the main observations to show that local redness, flare, and wheal are independent phenomenon.

Various injuries.

It is interesting and important to observe the many different forms of stimulus that provoke the triple response. It is the invariable response of the skin to injuries that produce an immediate response and that are not excessive ; an excessive stimulus or a stimulus that is many times repeated tends to produce ultimate blistering.

19h. *Mechanical stimulus.* The effects of stroke and scratch have already been seen. A simple needle prick suffices on many skins ; in all a wheal can be produced by pricking ten times in succession within an area of about a square millimetre.

19i. *Supercooling* [1] *and freezing.* The skin has a capacity to supercool, without freezing, in remarkable degree ; and this supercooling if adequate damages the skin. Use a copper bar $1\frac{1}{2}$ cm. square in section and about 15 cm. long, of which 5 cm. are imbedded in a wooden handle. Take a well-insulated jar or beaker of about 150 c.c. capacity ; pour

[1] See author's article in *Clinical Science*, vol. 5, 9.

in 100 c.c. of acetone, immerse the end of the copper bar, and add pieces of CO_2 snow until the temperature has reached $-25°$. Maintain this temperature. Bare a forearm, withdraw the bar and apply the end of it (wet with acetone) to the skin of the middle of the forearm ; keep it closely against the skin for precisely 10 seconds. (The temperature of the end of the bar will not rise more than $1°$ as a result of its contact with warm skin.) In the great majority of instances this will not freeze the skin, but a full wheal will appear, with itching and surrounding flare within 5 minutes. The temperature is important ; if $-20°$ is used, whealing occurs only rarely, and if $-30°$ is used the skin will usually freeze. In this observation, if the subject feels any pricking of the skin under the bar, the latter should be moved at once and cooling repeated elsewhere after re-immersing the bar in the cold acetone.

The effect of freezing, which also yields the triple response, may be observed by using the higher temperature of $-15°$. Freezing at lower temperatures (such as $-25°$) would introduce the fallacy that the reaction might be produced by cooling. But skin cannot be frozen readily at $-15°$ unless it is first prepared by increasing the water content of the horny layer. Soak the arm in warm water for 10 minutes and wipe it dry, otherwise the metal may freeze on to it. Take the metal bar out of the acetone at $15°$, quickly remove the acetone from its surface and at once apply the end to the skin. Notice the beginning of pricking, which may happen at once or be delayed for some seconds, and keep the bar in close contact for a further 20 seconds precisely. On taking off the bar you will find a creamy white square of skin hardened by the freezing. It will wheal and show a surrounding flare, usually with itching. Repeat this observation on the skin of the unsoaked arm, to show that a similar period of cooling at $-15°$ without freezing is insufficient to produce a wheal.

19j. *Heating.*[1] Take an inch of $\frac{1}{2}$ millimetre copper wire in a pair of forceps and heat the tip of the wire in a bunsen flame till it is red hot. Move it quickly from the flame and dab the hot end on the skin of the forearm (just on and off at once, a momentary contact). This will painlessly scorch the horny layer.

In a short time itching, wheal, and flare will appear.

19k. *Electrolysis.* Connect a 2 to 4 volt battery to two electrodes, the anode a large flat moist contact, the kathode a fine sewing needle. Run the needle through a flat cork so that its point just emerges ; hold this on the front of the forearm, allowing the back to rest on the flat anode. A few seconds after the circuit is made, pricking is felt around the needle point ; the measured current reaches 100 to 200 microamps in about 15 seconds, when the cork should be lifted. In a minute the arm will itch and a flare and shortly a little wheal will appear. The reaction is due to damage caused by electrolysis, hydrogen bubbles being liberated in the skin around the needle point.

19l. *Various poisons.* A large number of injurious substances lightly pricked into the skin produce the same response. Try a selection from the following, preferably testing the substances in duplicate or triplicate, but using a fresh needle for each substance employed, and removing the drop of fluid at once after the prick (hydrochloride acid 1 in 20, caustic soda 1 in 20, formaldehyde 1 in 10, atropine sulphate 1 in 50, morphine hydrochloride 1 in 100, chloroform). All the substances named give similar reactions. So will the stinging hair of a nettle, carefully cut out from the leaf and applied point downwards on the skin. The response is indistinguishable from that produced by histamine and gives the name of " nettle rash " to the corresponding clinical eruption.

[1] See also *Heart*, vol. 14, 141 ; *J. Physiol.*, vol. 72, 280.

Comment. All these reactions with whealing (described under *h* to *l*) disappear within about an hour. It will be clear that they must be due to a common factor ; that factor is injury, which, so it has been concluded, liberates a histamine-like substance from the cells of the skin.

19m. *H-substance in skin.*[1] Take several square centi-metres of guinea-pig's skin and harden it in a small quantity of absolute alcohol. Cut the skin into slender strips and replace these in the same alcohol. In a day or two pour off the alcohol into an evaporating basin and dry the extract at room temperature in a vacuum. Take up the residue in a few drops of distilled water. This solution, when pricked into the forearm, will produce the triple response.

Application

The experiments previously described are fundamental to a proper understanding of simple inflammation or acute reactions of the skin to injury of any kind, to cuts, scratches, " frostbite," burns, etc. ; they are equally important to an understanding of one of the commonest forms of skin eruption in patients, so-called " urticaria " or " nettle rash." Such rashes appear in a variety of circumstances, for example in infections, as a result of drug sensitivity, in reactions allied to anaphylaxis (food allergy), in response to cold or sunlight, when there are the appropriate predispositions. As in instances in which the skin had been damaged locally by mechanical or thermal agents, so also in all such instances of urticarial eruption we may conclude that the skin has been damaged and that the release of its cell contents sets up the response ; it is the manner in which the injury is effected that varies.

[1] *Heart,* vol. 14, 161.

20. VASODILATOR REACTION IN SKIN VESSELS TO COLD.

An important reaction of cutaneous vessels to cold is displayed as follows [1] :

20a. *Vasodilatation after cooling.* Fill a large beaker with crushed ice and enough water to fill the interstices. Place a sheet of cork or wood, through which a hole has been cut, over the mouth of the beaker ; lay a warm hand flat on this sheet. The subsequent observations can be made without other apparatus, but are more instructive if temperatures are taken from two fingers, fastening a thermal junction (see 11a), by means of a small piece of strapping on to the skin just above the nail of the finger that is to be immersed, and another similarly upon a control finger lying on the sheet of cork. It is also more satisfactory to keep the water in the beaker in movement, which can be done very readily by connecting an air pressure reservoir by rubber tubing to a pencil of porous cane, immersing the end of this cane below the finger ; the rising stream of bubbles will keep the water sufficiently stirred.

After noting that the two fingers are of more or less equal temperature, drop one through the hole, immersing the two terminal phalanges in the crushed ice, and in the middle of the stream of bubbles. Keep the finger immersed for 7 minutes, withdraw it, dry it very lightly, and resume the temperature observations. You will shortly find its temperature rising very fast and, about 10 minutes after withdrawing it, it will be glowing, perhaps throbbing, and hotter than any finger on the same hand. The temperature of this finger will continue raised for about a half hour. The control finger shows little change of temperature.

[1] See *Heart*, vol. 15, 177 and 351.

20b. *Vasodilatation during cooling.* If temperatures are being recorded, repeat this observation, but on this occasion note carefully what happens to your finger while it is immersed, and keep it immersed. On immersing the finger, its temperature will fall rapidly to 10° C., and the finger will become painful; the temperature will continue to fall more slowly and the pain will continue for some minutes. But about the 10th to 15th minute the pain will rather quickly fade away and the finger will become comfortable or even begin to feel warm. The thermal junction will show that the temperature has begun to rise, and it will continue to rise for about 5 minutes and in that time will have risen 3°, 5°, or more. The subsequent temperature often fluctuates but will never fall to that of the bath, and it rarely falls again as far as it fell at first. The rise of temperature is of such an order that, occurring while the finger is immersed, it indicates a conspicuous vasodilatation. When the finger is withdrawn finally it may become painful; the pain can be eased by recooling the finger.

20c. *A control.* To make sure that the phenomenon described is due to a change in the vessels of the finger and not to change of bath temperature, you may immerse the two index fingers simultaneously, stopping the circulation to the left arm at the same instant. It will then be found that whereas the usual reaction occurs in the right finger, the temperature of the left continues slowly to decline until it comes eventually very near to bath temperature, at which it will stay as long as it remains immersed.

20d. *Toes and ear tested.* The reaction described is not peculiar to the fingers; it occurs as clearly in the toes, and in the lobe of the ear; less constant effects are obtained from the end of the nose and chin. Skin of the forearm rarely displays it.

Comment. This reactive vasodilatation occurs in fingers that have lost sympathetic innervation (recently or remotely), and that have recently lost all innervation ; but it fails when nerves of the skin belonging to the posterior root system have been cut and have had time (6 to 10 days) to degenerate. Thus the reaction is similar, so far as its nervous mechanism is concerned, to that of the flare (see 19f). It is a response to an injury of the skin. It is usual for fingers submitted to prolonged cooling to be sore subsequently.

The reason why projecting parts display this reaction to advantage lies in part in their shape ; cooling in them occurs to a lower point. It lies in part in their unusual vascularity. But in the case of digits it lies *chiefly* in the presence in these of arteriolo-venule anastomoses (see 21).

20e. *Forearm tested.* That forearm skin is injured by cold and releases vasodilator substance, can be shown in a different way. Two small blocks of ice are pressed on the forearms for 5 minutes. The bloodflow to the left arm is now stopped by cuff pressure on the upper arm and both arms are immersed in water at 30° to warm the cooled areas. On the right arm the cooled area is red and its vessels dilated ; and the redness fades away in about 10 minutes. If the left arm is then released, it is flooded by reactive hyperaemia, which on fading leaves the cooled skin plainly marked out as a red area until about 10 minutes after the release. Thus the fading of the redness produced by cold is not produced by the rewarming of the skin ; it is due to removal of substance originally released by the cold-injury (see the more pronounced effects of supercooling in 19i).

Application

The vasodilatation described in the finger is important ; it illustrates part of a protective mechanism against cold ; it arises out of injury and comes into play as soon as damage

by cold begins ; thus greater damage tends to be avoided. The reaction is not confined to temperatures at or near 0° ; it can be traced as a lessening response to temperatures ranging as high as 15° to 18°, and is therefore a reaction coming frequently into play in northern European climates.

It is absent in cases of old standing injuries of nerves supplying fingers and toes. Largely for this reason the extremities in such subjects become persistently cold and show disturbances of nutrition and of damage.

21. ARTERIOLO-VENULE ANASTOMOSES

In certain parts of the skin, curious and important anastomoses, first described by Sucquet, exist between arterioles and venules. The anastomoses have very muscular and highly innervated walls. They are found particularly in the tissues of the tips of the digits, the nail bed, and pulp ; and to a lesser extent in the skin of the ventral surfaces of the fingers and toes, and in that of the palms and soles. They form special sluice gates bringing when necessary an abundance of blood to the extremities.[1]

21a. *Anastomoses and reaction to ice.* When a finger is immersed in crushed ice, the rise of temperature which comes (see 20b) can be shown to be much greater and to occur earlier at the tip of the finger than at the middle of the finger. Use two thermal junctions for this purpose, fixing one on the pulp of the finger and another in the middle of its dorsal or ventral surface.

21b. *Anastomoses and released circulation.* In a cool room, attach thermal junctions to finger tip, middle of finger, and dorsal surface of hand. Shut off the circulation to the arm

[1] See *Heart*, vol. 15, 385.

for 10 or more minutes, noting the falls of temperature ; they become greater as you pass to the periphery. Now release the flow and you will note that the temperature rises quickest at the tip of the finger, where it often comes to ride above that of the remaining points. (Another example illustrating the sluice gates of the finger tips is given in 11c.)

22. REACTIVE HYPERAEMIA

Though the results of the tests here described will in general be shown under any ordinary class room conditions, the reaction is apt to be delayed and less conspicuous when the limbs become cold and the arterioles assume greater tone. Strictly the tests should be done on limbs maintained at a temperature of 34° or 35° C., but it suffices when testing normal young subjects to use limbs that are naturally warm and at a room temperature about 20° to 22° C. Allow an interval of a few minutes to intervene between tests.[1]

22a. *The visible reaction.* Wrap a pneumatic cuff snugly around the upper arm, lift the hand above the head and, when the veins are empty, arrest the circulation to the arm by throwing a pressure of 180 to 200 mm. Hg into the cuff. Place the limb in a resting position, maintain the arrest for 5 minutes, and then abruptly release the cuff pressure, while watching the limb. Note the bright red flush that rapidly covers the whole surface of the limb ; it does not spread from the cuff to the fingers, but appears almost simultaneously over the whole arm, which is all fully reddened within 2 to 5 seconds. Take off the cuff and note that the flush extends to the precise upper limit of armlet pressure, where

[1] See *Heart*, vol. 12, 73.

it ends in a sharply defined margin. Keep the two arms side by side, the flushed arm will be seen to return to its normal colour in about 3 minutes.

Comment. This phenomenon is called "reactive hyperaemia." It is not a reaction to pressure, but is a compensatory process discharging the circulatory debt to the tissues built up during the period of bloodflow arrest.

22b. *Period of arrest varied.* The hands being of equal temperature, treat both arms similarly but stop the circulation in one 2 minutes before the other, releasing both together at the end of 5 minutes. Note that the flush becomes deeper and lasts longer in the arm to which the bloodflow has been arrested the longer.

Comment. The discharge of the debt is related to the debt's magnitude.

22c. *Alternative method.* Alternatively, stop the circulation by means of a cuff placed on the forearm. Then place a second cuff on the upper arm ; stop the circulation at this level after 5 minutes, then deflate and remove the lower cuff, and maintain the pressure in the upper cuff for another 5 or 10 minutes. Release the upper cuff and note the brilliance of the resulting reaction. In a short time the colour of the upper arm begins to fade, while the forearm retains its deeper colour for some time longer up to the line to which the top edge of the lower cuff extended.

In the reactions to these longer arrests tingling (" pins and needles ") is conspicuous. It begins at the finger tips, spreads up them, and lasts several minutes, before gradually disappearing.

22d. *Reaction to venous congestion.* Throw a pressure of 60 mm. Hg into a cuff on the upper arm and note how the skin becomes deeply congested and cyanosed during the

next 5 minutes. Release and remove the cuff at the end of this time and the arm reddens to the level where the top of the cuff rested.

Comment. Arrest of bloodflow to the skin is not requisite to a subsequent reaction; a reduction of bloodflow suffices to establish a debt that is subsequently compensated.

22e. *Minimal pressure required.* Press the elbow upon an open pneumatic cuff, maintaining a pressure of 50 or 60 mm. Hg within the bag. This pressure exerted directly is adequate to stop, or so greatly to impede, bloodflow to the skin, that, maintained for 5 minutes, it is followed by obvious reactive hyperaemia.

Comment. Any part of the skin submitted to much pressure, for example the soles of the feet while standing still, or the buttocks while sitting, subsequently display the reaction.

22f. *Mechanism of reactive hyperaemia.* The reaction of the vessels is independent of the nervous system, local and central; thus the reaction occurs equally well in skin to which all nerve fibres have been cut and have degenerated.

The vessels are considered to respond to vasodilator metabolites released by the skin and accumulating during the period of arrested bloodflow, and the flush supposedly continues until this accumulation is dispersed. It has been shown that the loss of tone in the vessels occurs during the period of circulatory arrest.

The vessels concerned include vessels of all orders. The flush that comes is sharply defined and marks out precisely the upper border of skin involved in cuff pressure to within a fraction of a millimetre, thus showing that minute vessels are actively concerned. That arterioles are involved can be shown by arresting the circulation to the hand by a cuff at the

wrist, then rendering the whole arm cyanotic by imposing 70 mm. pressure on the upper arm, and lastly by releasing the wrist cuff; the resulting reactive hyperaemia of hand and wrist gives a long continued bright red skin, in contrast to the purple skin of the rest of the congested arm.

The veins can be shown to be concerned by stopping the bloodflow to an arm for 10 minutes, releasing this and at once throwing a pressure of 50 mm. on to the veins of both arms, the veins, though under equal pressure on the two sides, swell more on the side to which bloodflow has previously been arrested. The arms should be kept equally warm in this test.

Application

Reactive hyperaemia by compensating for a circulatory debt safeguards the skin from nutritional damage. In some patients who are paralysed, or are so feeble that they are unable to move, the skin over sacrum and heels is endangered if they are allowed to lie supine without being frequently moved; for movement allows reactive hyperaemia to occur. Without this relief the skin of these parts will die and slough away, forming so-called bed-sores.

The manner in which the flush occurs upon the skin of a limb in test 22a is very valuable in cases in which the circulation to a part of the limb (fingers, toes, foot, etc.) is defective. For in the test the flush spreads at once through all normal parts, but is delayed in and thus picks out the parts deficiently supplied. Thus the test is used to define the extent of obliterative arterial disease, and to indicate the limits of skin that may be used safely to form flaps in amputations in these cases. But it is very important in testing such pathological limbs, which are often cold when first seen, to warm them thoroughly to 35° before making the test; for coldness by increasing local arterial tone will delay the return of blood-flow. An equally important preliminary is to drain the

blood from the limb by raising it, for blood held in the minute vessels for 5 minutes loses some of its plasma and tends to become sticky ; this will also delay the reaction.

In grafting skin from arm to nose in plastic surgery, the vascular union of the arm skin to the face may be tested by arresting the blood flow to the arm and releasing it. The graft will not participate in reactive hyperaemia if the vascular union is satisfactory.

23. ULTRAVIOLET LIGHT

The dose of ultraviolet needed to produce the effects to be described cannot be stated precisely, because different skins, with their different pigment content, react variably. It will be necessary to produce something more than simple reddening of the skin, and an overdose that will blister the skin is to be avoided. A preliminary and graded exposure should be made, and is in itself instructive. Use a mercury vapour lamp adapted to 200 or 240 volts and carrying a current of about 7 amps.[1]

23a. *The skin reaction.* Take a piece of thick black paper (4 × 8 cm.) and cut out of its middle a rectangle 1 cm. wide and 4 cm. long. Place this mask on the front and in the length of the forearm, and fasten it by its edges lightly in place with adhesive strapping. Cover all the skin with the exception of the rectangle with black cloths. Now bring the burner of the quartz lamp to within 18 inches of the skin. Mark the exposed strip of skin, dividing it into 4 equal parts ; cover 3 of these parts with a square of black paper. Now strike the lamp and expose the first strip of skin for 2 minutes ; expose this and the next strip for 2 more minutes ;

[1] See *Heart*, vol. 13, 203.

proceed in the same way till all 4 strips have been exposed ; the first will then have experienced the light for 8 minutes and the last for 2 minutes.

According to the susceptibility of the skin, the reaction described will come with 2, 4, 6, or 8 minute exposure ; usually it will come with the exposure of 4 minutes or more. On taking off the mask, there may be a little heat reddening of the skin, but this will pass away. The first sign of U.V. reaction will appear in $\frac{1}{2}$ to 1 hour as a faint, and usually patchy, redness of the skin ; this will deepen and become uniform, and with sharp margins will precisely mark out the area of skin exposed. The rectangle receiving a small exposure will show weaker and more delayed reaction ; that receiving a longer one will show an earlier and more intense reaction. The differences in intensity will be most distinct about 2 to 3 hours after the exposure.

23b. *Congestion displays increased bloodflow.* When the reaction just described has developed, congest the arm by throwing pressure on to the veins (see 19d). The rectangle will show up as a sharply defined red rectangle upon a purple background, indicating increased bloodflow through its vessels, but this increase is not usually so great as to allow a heightened temperature of the skin or capillary pulsation to be detected.

23c. *Circulatory arrest displays capillary response.* If the circulation to the arm is arrested (see 19c), the reaction will soon show up as a purple patch on a paler skin ; express the blood from it with a finger and it will flow back again, showing that these minute vessels have lost their usual tone.

Comment. These tests and the sharpness of the margins of the affected area show that the reaction is occurring in and is confined to the minute vessels of the skin, including the very terminal arterioles.

23d. *Exposure for severe reaction.* Next day, the margin of those parts of this skin that have been exposed sufficiently, will become a little less clearly defined, and a little tender. Note which part of the line is in this state. Usually it will be that exposed for 8 minutes. If the corresponding skin is very tender use this exposure again ; if not tender, or more than slightly so, use an exposure of 10 or 12 minutes in the next exercise.

23e. *Diffusion flush displayed.* Cut out from a sheet of black paper with a sharp knife two small rectangles (Fig. 7) side by side in their length, leaving a narrow band of paper 1½ mm. wide between the two. Expose the skin through this mask for the time determined in the last test and examine
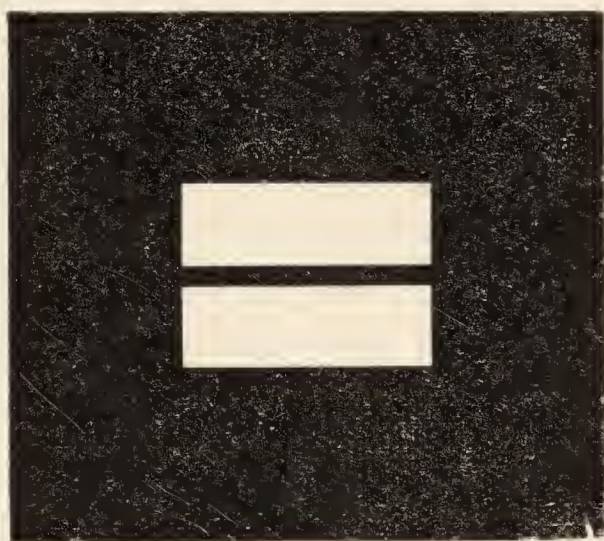
FIG. 7.

the skin next day. It will be found that the redness has developed not only on the exposed skin but has extended at all its margins for 2 to 3 mm., blurring them and tending to obliterate the protected 1½ mm. central band of originally unaffected skin. Not infrequently with the longer exposures the marginal diffusion of the effect (diffusion flush) proceeds farther along a narrow tongue that marks for a short distance the course of a lymphatic channel.

Comment. The diffusion of the reaction beyond the boundaries of the skin actually exposed, and especially its movement along lymphatic channels, demonstrates the release of substances that dilate the minute vessels with which they come into contact.

23f. *Progress of severe reaction.* Follow the progress of this inflamed skin. In exposures of about 8 minutes the skin is just detectibly swollen next day and distinctly tender. The diffusion flush, lying beyond the area exposed, fades away within 2 or 3 days and by the 4th to 6th day the skin is losing its redness and is becoming pigmented ; a few days later it begins to peel. After peeling the skin will again develop local pigmentation and this will last sometimes for weeks or even months. With longer exposures swelling and tenderness are more conspicuous and subsidence of the reaction is slower. In such it is usual to notice 2 or 3 days after irradiation that the deep redness gives place to paleness or even to a yellow colour, a change associated with accumulation of white blood cells in the affected skin. Very long exposures are apt to blister the skin.

When the skin is red or obviously tender it is in a state described in more detail elsewhere (see 24), and is useful for certain tests relating to pain.

Associated reactions

The ultraviolet light reactions here described are completely relevant to the reactions of white skin exposed to strong sunlight, which may thus be studied in the convenient conditions of a laboratory. But they have a much wider significance. The reaction has not the acuteness, neither has it the simplicity, of the triple response. It is a delayed and more prolonged inflammation and results in leucocytic infiltration of the skin, in multiplication of epidermis cells (resulting in peeling), and in pigmentation. Like the triple

response, from which however it is to be regarded as distinct, this subacute inflammation is a characteristic response of skin damaged in a number of different ways. Freezing of the skin (see 19i) to a certain hardness produces very similar after-effects. Certain spontaneous eruptions of the skin belong to the same class of inflammatory change.

24. ERYTHRALGIA

There is a curious and important state of skin, described under this term, of which the most familiar example is a sunlight burn. It presents deep redness of the skin, with or without slight swelling, and a state of tenderness.[1]

24a. *Making skin erythralgic.* Two days before this exercise expose a few square centimetres of skin of the forearm, or preferably the dorsum of the foot, to ultraviolet light, using one of the longer exposures (see 23d).

On the same day freeze a small patch of skin of the forearm. First be sure the skin is quite dry, if not, dry it with methylated spirit and a towel. Use the copper bar taken out of acetone at $-30°$ and apply it to the arm, maintain it there for precisely 3 seconds after freezing starts. It will form a hard scale of frost in the skin, which will wheal.

The areas treated with ultraviolet light and by freezing will be in very similar states 2 days after the injury, and will remain so for several more days. They will both be of deep red colour, will display a surrounding diffusion flush, may be perceptibly swollen, and will be tender to slight friction (erythralgia).

24b. *Erythralgia and needle pricks.* Test the skin so affected with a fine needle, and note that it responds to pricks

[1] See *Clinical Science*, vol. 1, 39 and 175.

that are too light to awaken pain in surrounding unaffected skin ; note too that the pain response when it comes is of unusual intensity.

24c. *Erythralgia and warmth.* Take a mass of copper or brass ; it should be large so that its temperature will not change quickly, and it should have a flat surface. A 250–500 g. weight will do. Immerse this for several minutes in water at 43°. Take it out, dry it and apply the flat surface to unaffected skin ; it is pleasantly warm but gives at this, or very near to this, temperature, a just perceptible sting. At 44° it will sting the skin quite definitely, at 41° it will feel merely warm. Now transfer the metal at 41° from unaffected to reddened skin, and almost at once you will need to withdraw it on account of strong burning pain. After an interval test the skin again and you will find that the sting is perceptible when the metal is at comparatively low temperatures, namely around 34°, a little more or a little less. The temperature of the metal required to induce pain varies with the initial temperature of the skin, but 35° will always give pain with lesions such as are here used.

The severer the lesion the less will be the warmth required to cause burning pain in the skin. With severe U.V. burns, with severe freezes, and in the familiar instance of heat burns, the warmth required is no more than the usual natural warmth of the skin. In such instances the skin will give burning pain " spontaneously." When skin is scalded or burnt, pain comes at once, but the pain *which continues* subsequently, though of the same kind, is no longer connected directly with heat, but with an altered state of the skin, which is common to all forms of injury here described.

24d. *Erythralgia from scratches.* Mark out an area 2 centimetres square on the forearm and on this skin make 10 vertical and parallel scratches with a needle point, without

breaking the skin ; scratch another 10 times horizontally and another 10 times obliquely. In about 15 or 20 minutes you may perceive in this area a little spontaneous burning ; usually if you place the metal at 41° upon it, stinging pain will result. Children, who have scratched their legs, will often cry when they sit in their baths the same evening. A fresh cut in the skin is scarcely tender, but it becomes so and it becomes hypersensitive to heat within 5 or more minutes. All these phenomena have the same underlying basis, the injured skin has become as we say " erythralgic ".

24e. *Erythralgia and cold.* Return to the U.V. burn or freeze. Place the end of a metal rod, taken out of ice-cold water, against it, and this also will bring burning pain.

24f. *Recurrent pain.* With a finger, stroke the most tender of the reddened areas once, rather firmly and quickly. As your stroking finger crosses it, pain is experienced, but subsides at once. Notice however that after a clear interval of about 10 seconds, a similar pain re-appears (recurrent pain) and lasts for 1 to 3 minutes. Probably, the first pain is due to direct excitation of the hyper-excitable nerve endings, and the second to the increased discharge of a stable pain-producing substance into the inter-cellular spaces. For it has been found that if this observation is made while the circulation to the arm is arrested, the first pain subsides as before, but the recurrent pain outlasts the period of circulatory arrest.

24g. *Tension and pain.* Place a finger on either side of the reddened skin and stretch it. This produces pain. If an ultraviolet burn has been made on the foot, it will often be found that if the foot is warm and hangs down it pains, but if the subject lies supine the pain vanishes. This reaction to posture requires rather critical conditions. It is a tension

effect, the tension in the skin increasing with the venous congestion in the erect posture. Throw 60 mm. Hg pressure onto the veins of the leg and it will have the same effect as hanging the leg down ; and when pain comes in these circumstances it can be stopped by blocking the common femoral artery.

Application

An erythralgic condition of the skin is frequent in a number of conditions in which skin has been injured. Skin that has been damaged accidentally by physical or chemical agents (chloroform, mustard oil) is unusually sensitive to warmth and to unusual cold. The same state of skin is met with in a large number of different affections, including painful chilblains, frostbite, lesions arising out of defective blood supply, shingles and many other small inflammatory lesions of the skin. When the feet are affected the patients often insist on keeping their feet uncovered at night and are relieved in the day by lying down and raising their feet.

25.   GOOSE SKIN AND SOME AXON REFLEXES

The pilomotor reaction commonly called " goose skin " is familiar.

To observe it most readily the skin should be watched in a good light that reaches the skin almost in the plane of its surface. Contraction of the pilomotor muscles lifts the papillae of the skin, which then cast tiny shadows that are easily seen. This method of identifying goose skin is much easier than that of watching erection of the actual hairs.

Goose skin can be produced in one of a number of distinct ways.[1]

[1] See *J. Physiol.*, vol. 64, 87 ; *Heart*, vol. 15, 151 ; *Clinical Science*, vol. 3, 337.

25a. *Goose skin through central reflex.* As we ordinarily recognise it, goose skin is a spinal cord reflex. Afferent impulses travel from the skin and efferent impulses pass out of the cord through the sympathetic pilomotor nerves. The reflex is most easily induced as an accompaniment of shivering in fever or after prolonged exposure to cold.

If the body is unclothed in a cool room, conditions predisposing to the reflex, it may often be aroused by rough friction of the skin, or by the application of a block of ice or of a hot stimulus to the skin, at some distant point. Stimuli applied to large surfaces are the most effective and the back of the neck is one of the areas from which general goose skin is most easily provoked. Pinching the border of the trapezius muscle is another favourite stimulus.

The latent period is brief; the response is often unilateral when the stimulus is unilateral; it tends to spread over the trunk in steps from one region to an adjacent one. The extent of the goose skin is sometimes useful in mapping out areas to which the sympathetic supply has been lost, but, unhappily the response is capricious and consequently sweating in response to heat (11b) is more serviceable for this purpose.

25b. *Goose skin by direct response of end apparatus.* If the skin is stroked—usually, but not always, a heavy stroke is necessary—or if the skin is slapped with a flat ruler, or if ice is laid upon it for a minute or so, these stimuli are all followed by goose skin, strictly confined to the area stimulated. Goose skin also occurs locally when adrenaline is introduced into the skin (see 33g).

All these examples of the local response occur after the pilomotor nerves to the skin have been divided and have been given time to degenerate. The response is due to direct stimulation of the end apparatus.

25c. *Goose skin through axon reflex.* An instance of an

axon reflex involving the arterioles of the skin and produced through nerve fibres of the posterior root system has been given (see 19f).

Use a du Bois Reymond coil and twin platinum electrodes. Stimulate the skin of the back of the forearm in an appropriate light; it is necessary to use a current strength that is decidedly painful. In a few seconds the hair papillae rise over an area surrounding the point of stimulation; the goose skin grows in prominence as the current is continued and spreads till it covers an area 5 or 6 cm. in diameter. On the leg it is often larger. The central area of goose skin is compact, that is to say, every hair in the area is affected, but they are less strongly affected towards the periphery. If the electrodes are moved a centimetre on the skin, then an extra band of goose skin will be added on the corresponding side and a similar band will be subtracted on the other. Note that a given hair can be erected by stimulating the skin within 1 or 2 cm. from it in any direction. The central area is never quite circular, and often a little radiating promontory of goose skin will jut out a centimetre or more, and an occasional outlying islet of goose skin may be seen. The area of goose skin outlasts stimulation for a minute or more, and is exactly repeated, with promontory or islet, if the same spot is re-stimulated.

The following three exercises test the nervous mechanism:

25d. *Intracutaneous procaine.* Inject into the skin where the electrodes have been 0·02 to 0·03 c.c. of 2% procaine (19f). Inject intradermally to raise a little wheal 5 mm. in diameter. You will now find that you can stimulate the centre of this wheal and the current strength can be raised without your feeling it. You will no longer obtain a trace of goose skin, which when it occurs is due to stimulation of the plexus of pilomotor nerves directly beneath the electrodes and to spread of impulses through this plexus.

25e. *Nerve block.* Thus, this local goose skin can be raised in skin to which the cutaneous nerves have been blocked by procaine (see 26c). It can be obtained from a piece of skin freshly excised in surgical operation. But it cannot be raised if the cutaneous nerve has been cut and time allowed for degeneration ; neither can it be obtained from skin similarly deprived of sympathetic nerves only. It is produced as an axon reflex in the sympathetic nerve plexuses of the skin.

25f. *Procaine barrier.* If procaine is injected intradermally, and the injection is carried forward for several centimetres along one line, it will be found that this line will not be passed by the reaction. Scars in the skin form similar barriers, although the skin may be perfectly sentient on either side. The plexus in which the reflex occurs is in the skin and not beneath it.

Comment. These goose skin reactions have more than theoretical interest. The central reflex will map out areas to which the sympathetic nerve supply has been lost, whether through preganglionic or postganglionic damage. Faradism applied locally identifies the skin to which the nerves are not only severed but degenerate.

25g. *Sweating reflex (local).* An axon reflex in plexuses of sweat nerves in the skin is aroused by the same faradic stimulus.

In a good light tiny points of sweat may be seen crowded around the electrodes during and after simulation but it is best to use a sweat indicator. Paint an iodine indicator on the skin (alcohol 90 c.c., castor oil 10 c.c., and iodine 1·5 g.) [1] and when this is dry blow finely powdered starch

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[1] An effective indicator is quinizarin 2 : 6 disulphonic acid ; it is made up ready for use as quinizarin compound (B. & W.) and is used as a dusting powder.

onto it.   Stimulate within this area, and wherever sweating occurs around the electrodes the starch will become blue.

Local anaesthetisation stops the response, anaesthetising the cutaneous nerves to the area does not.   It is abolished by degeneration of the sympathetic nerves, following destruction or extirpation of the appropriate sympathetic ganglion.

Application

Goose skin and sweat reactions are used to test the intactness or otherwise of the corresponding sympathetic nerves. The foregoing tests may be used to differentiate between lesions that have merely interrupted the main channels and those that have led to degeneration of the cutaneous nerve plexuses.

26.   PARALYSIS OF CUTANEOUS NERVES

Forearms that are not thickly covered with fat are most suitable ;   the amount of fat present can be estimated by pinching it up, and in a fold it should not exceed one or at most two centimetres.

26a. *Cutaneous nerve located.*   Use a faradic coil with twin platinum electrodes, and a current strength that is clearly perceptible when the electrodes are placed on the skin of the forearm.   Stimulate the skin in this way while moving the electrodes slowly across the front of the upper arm.   For the most part you should feel local pricking and tingling from this current ;   but, as the electrodes travel, sooner or later the sensation will change to a fluttering that is referred down the forearm, probably as far as the wrist.   You are then stimulating a cutaneous nerve trunk, and the sensation is referred

to the periphery of the nerve's distribution.[1]   Working carefully there is no difficulty in accurately ascertaining the position of the nerve and in following its course ; mark the line of it on the skin in ink. You may sometimes mark out 5, 10, or more centimetres of its course and even identify a main branching.

26b. *Sensory territory mapped under faradism.* While the current is running into the nerve, its territory may be mapped with accuracy by using a camel hair brush. Tactile sense is reduced over the whole territory during the passage of the current, and often for a little time afterwards. Mark out the limits of this territory on the arm.

26c. *Nerve to forearm skin blocked.* Take a hypodermic syringe filled with 2% procaine and 1 in 10,000 adrenaline, all sterile. Pierce the skin directly in the path of the nerve, and preferably where you have traced it to its emergence from the deep fascia. Push the needle in at an angle of 45° for about 1 cm. and inject 1 c.c. of solution ; push it on another $\frac{1}{2}$ cm. and repeat the injection. Withdraw the needle and shut off the circulation to the limb. This procedure will usually paralyse the nerve you have found within 5 or 10 minutes. If it has not done so repeat the injection, passing the needle a little deeper, but always as strictly as possible in the marked line of the nerve.

When you have succeeded, release the circulation (release it in any case at the end of 10 minutes) ; and note the loss of tactile and pain sense and that there is usually a central area of total loss as well as a larger area of partial loss.

The area will not be as extensive as that marked out during the passage of the current, for the nerve territories overlap

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[1] Trotter & Davies, *J. Physiol.*, vol. 38, 134. Fuller information relating to this and the following sections (down to 30) will be found in the author's book *Pain,* 1942.

considerably. Indeed, if you paralyse a small branch you may be unable to detect much or any area of sensory defect, until you paralyse its neighbour also.

26d. *Ulnar nerve anaesthetised.* Under supervision you may inject the ulnar nerve at the elbow. The nerve can be felt as a hard cord lying in the groove behind the inner condyle of the humerus. Use a stronger needle and pierce the skin over the upper part of the groove ; drive the needle on immediately anterior to the condyle side of the nerve, until it makes contact with the condyle ; then inject 2 c.c. of the local anaesthetic, withdraw the needle a few millimetres and inject 2 c.c. again, withdraw the needle and stop the circulation to the limb. Do not attempt to inject the nerve itself ; if you do inject it there will be pain on recovery.

This procedure will usually paralyse the ulnar nerve. If it fails to do so, do not repeat the injection on the same day, but try another subject. Paralysis of the nerve will increase the temperature of the little finger, especially if the hand is originally cool ; it will give the characteristic sensory loss, usually over the whole of the 5th and inner side of the 4th finger, and over the ulnar side of the hand. It will weaken adduction of the thumb, and of extension of the terminal joints of the little finger, which are held a little flexed. It will stop any sweating that is occurring on the ulnar side of the hand.

26e. *Nerve blocked by asphyxia.* The ulnar nerve may also be paralysed by leaning the inner side of the elbow on a pneumatic pad under a pressure of 150 mm. Hg ; but the paralysis takes 25 to 30 minutes to occur, and holds only while pressure is maintained.

In testing touch and pain sense it is convenient to employ coarse hairs, such for instance as are found in a cat's whiskers. Choose a bristle that when pressed on a balance registers a weight of 1 g. or 2 g. Choose stronger bristles registering 2 g. to 4 g. A bristle can often be strengthened to precisely the right degree by shortening it. To the ends of some of the stronger bristles attach by means of hot wax in their length points of very fine sewing needles. The bristles, with or without needle points attached, may be mounted by sticking them at right angles onto small glass tube handles.

27a. *Touch sense.* Use the lightest bristles and make contacts with the skin of the fingers. Each touch is felt distinctly, none fails. Similarly test the skin of the upper arm ; many will fail, for this skin is less richly supplied by touch fibres. Test the back of the forearm very closely and note the frequent relation of the " touch spots " to the hair bulbs ; touch nerves are numerous around these. Notice too that the slightest movement of a hair is at once registered.

Test the accuracy with which a touch can be located by a blindfold subject.

27b. *Pain sense.* Use a 2 g. needle and test the fingers. For the most part only touch will be registered, but from point to point pain will be felt. More pain points will be found with a 4 g. than with a 2 g. needle. Pain points are relatively infrequent on the nose and are said to be more frequent on the upper arm than on the fingers.

27c. *Cold and warm spots.* In testing for cold and warm spots use brass rods about 5 mm. diam. but reduced at their

flat ends to 1 mm. diam. Test the warm skin only (skin at about 34° C.) and maintain the rods at the proper temperatures, namely 42° C. and 25° C., by keeping them immersed in water at these temperatures, quickly drying the end by touching blotting paper just before applying it to the skin.

Cold spots on the skin of the back of the hand are easy to find, but some are much more conspicuous than others ; mark a few of these on the skin and you will find that they are to be found on repetition. Warm spots too are not difficult to discriminate, though less easy than cold spots.

27d. *Sensory dissociation.* The mucous membrane of the nose is devoid of touch nerves and of warm nerves. Every contact that is here felt is either painful or cold, according to the kind of contact. The skin just within the nostril has touch and warm sense in addition.

27e. *Two pains.* Use a 2 g. needle on the skin at the base of a finger nail. The contact will give either a touch or a faint prick. Notice however that the contact is followed after an appreciable interval of delay by a second sensation, a little flash of pain, often more conspicuous than the first. The occurrence of two flashes of pain are thought to result from conduction of the impulses through groups of fast and slow conducting nerve fibres. The interval between the two increases as distance from the spinal cord increases, and is most conspicuous when the stimulus is applied to the foot.

A brass rod at 65° C. brought into momentary contact with the skin forms a very adequate form of pain stimulus in eliciting the two pains just described.

Application

Disturbances of touch, pain, warm and cold sense are common to many diseases of the nervous system, as is well known.

Of the two skin pains in response to prick, the first is lost in tabes dorsalis, giving rise to an apparent delay in the response to prick.

28.   SKIN PAIN

Pain that comes from the skin and the exposed mucous membranes is always of one character, but it can vary in duration.   Common parlance describes it as " pricking " if short and as " burning " if long.

28a. *Prick sensation aroused by distinct methods.*   The agency producing a transient skin pain cannot be recognised by attending to the pain.   Fasten a silk thread onto a hair with a little collodion, tweak the thread and you will produce a little pain indistinguishable from a needle prick.   Bend a (0·25 mm.) constantan wire,[1] 5 cm. long, to an acute angle and heat it by passing through it a current of about 1 amp. The wire should become too hot to handle, but not glowing. Mount it suitably and bring the hot point of the bend into very transient contact with the skin.   A blindfolded subject cannot discriminate the pain thus produced from a needle prick, or from a single galvanic shock.

28b. *Burning pain aroused by distinct methods.*   The agency producing skin pain of longer duration cannot be recognised by attending to the pain.   Bring the bend of wire already described (see 28a) through a flat piece of cork and lay the cork on the skin.   Turn on the current for about a second.   Burning pain will be felt.   An exactly similar pain will be felt if the thread attached to a hair is pulled through a hole in a similar cork ; or if a tiny fold of skin is caught up and pinched in fine

[1] Eureka W. G., 32.

forceps. In testing the skin in these three ways discrimination of the pain producing agency will be found to depend, not on the pain, but on hints gained from a sense of warmth if the wire is heated too long, or from the nature of the contacts if a hair is pulled upon without first attaching it to a thread, etc. The open end of a tube containing chloroform, held on the skin, soon gives burning pain, and its character is the same as that arising in response to other agencies described.

28c. *Skin pain has a distinctive character.* Pricking and burning pain have the same character. Tweak the hair and a prick is felt, put long tension on it and burning is felt. Stimuli of intermediate length will convince you that the character of the pain does not change with its duration. A similar observation on the transition may be made by using the hot wire for varying times. Skin pain has always the same distinctive character.

Application

Pain having the distinctive character described comes from skin, certain mucous membrane, and from the nerves supplying these structures, and from no other tissues. The character is consequently very helpful in locating the structure from which the pain comes.

29. DEEP PAIN

29a. *Web pain.* Pinch the web of skin between 4th and 5th fingers between finger and thumb. As pressure is increased a peculiar and disagreeable pain is felt that is continuous, but quite distinct from that described as burning.

29b. *Tendon pain.* A pain of precisely the same character can be produced by firmly squeezing the tendo Achillis. Tendon always gives this kind of pain and no other. Use a fine sterile hypodermic needle and anaesthetise a little patch of skin over the tendo Achillis ; then drive the needle on into the tendon. The tendon pain will be felt again ; and it will be repeated in the same form, though more prolonged, if 0·2 c.c. of 5% sterile saline is injected into it.

29c. *Muscle pain.* Alternatively, use muscle. Squeeze the belly of a muscle, such as the sternomastoid or a muscle of the forearm. The pain is very similar to, if not identical with, that produced from tendon. The pain produced by squeezing may be compared with that produced by injecting 5% saline (as described for tendon) ; and it may be compared with that produced by muscle working while the blood supply is cut off (see 31a). In all instances the pain is readily recognised as of one kind. It is another instance of deep pain.

29d. *Mucous membranes.* Test pain derived from the conjunctiva by touching the sclerotic with a 2 g. hair, and test the nasal mucous membrane with a needle, with a view to determining whether these pains are to be classed with " skin " or " deep " pain.

Application

The pain from deep structures is sufficiently distinctive greatly to help in locating its origin. The methods described allow pain to be provoked at will in patients, so that they may compare such pain with spontaneous pain which they experience.

30a. If the upper part of the trapezius muscle is squeezed, pain is felt by many in the occipital region ; if the lower part of the triceps is squeezed, many feel pain referred below the elbow. These are simple examples of faulty localisation such as is usual with muscle pain.

These observations are of course crude, because the muscle pain produced by squeezing is complicated by sensations similarly derived from the skin. They can be rendered more exact by injecting the corresponding muscles with 0·3 c.c. of 5% saline. Among the best muscles to use for this purpose are the triceps, or the belly of the anterior crural muscles just above the middle of the leg. In the latter the pain is felt locally, but in many is referred to the front of the ankle. It is reference which accounts for pain in this situation following upon the unusual exercise of the anterior crural muscles in skating.

30b. It is the rule for pain to be localised inaccurately whenever it arises from a deep lying structure, and the deeper the structure lies the more likely is this reference of pain to happen. The pain when referred, may be referred to any part of the region supplied by the nerves stimulated ; if the pain is strong it will be referred to the whole region. Thus the pain has a segmental distribution.

Identify the spine of the 7th cervical vertebra. Anaesthetise a little patch of skin below this spine and a few millimetres to the left of it. Use a long hypodermic needle, pass it through the skin and directly forwards, just to the left of the middle line, until you reach the interspinous ligament ; drive the needle on to a total depth of 2 or 3 cm. to reach the deeper interspinous ligament, and inject 0·3 c.c. of 5%

saline. This injection is followed at once by pain that, while felt near the injection, is also referred to the left breast and down the inside of the left elbow and forearm. If the injection has been made in the middle line the pain will be bilateral. It lasts continuously for a few minutes and is recognised by those who have experienced pain of cardiac origin (anginal pain) to be indistinguishable from this. The reference is along the 8th cervical segment.

This observation is a most instructive one ; the diffuseness of the pain and the difficulty of precisely locating it may be noticed.

30c. A similar injection of the ligament below the 1st lumbar spine gives pain resembling that of renal colic, pain referred into iliac fossa and testicle of the same side, accompanied by a little rigidity of the muscles in the fossa and by retraction of the testicle if the pain is at all strong.

It should perhaps be emphasised that the injections here described, carefully done under ordinary antiseptic precautions, are quite safe to undertake and give rise to no more than temporary discomfort.

Application

The applications of the foregoing observations on pain are very numerous ; but most important is the understanding given of pain by personal experiences of pain and its accompanying phenomena. The references of pain derived from deep sources in disease are numerous and many of them characteristic ; the present observations exemplify them.

31. PAIN FROM MUSCLES WORKING WITH DEFICIENT BLOOD SUPPLY [1]

An interval of at least 5 minutes rest should be allowed after each of the following tests :

31a. *Basal experiment.* The subject grasps a broomstick or the edges of a small table with his two hands, having upon one upper arm a pneumatic cuff connected in readiness to occlude the arteries of that arm. Pressure is raised abruptly and maintained in the cuff, while the subject momentarily and tightly grasps the object held, the movements being repeated rhythmically at the rate of one a second and with both hands.

Pain will begin to be experienced in the arm to which the circulation is interrupted, and in this one only. It comes in the forearm and perhaps the thenar eminence after 20 to 30 seconds ; it increases steadily as the movements are continued, becoming very uncomfortable at 50 to 70 seconds. The exercise should then end. The subject will note that the pain is still continuing unchanged a minute or more later if the pressure in the cuff is maintained ; he will also note that the forearm and perhaps the thenar eminence have become a little tender to deep pressure, although the underlying muscles are quite relaxed. But on releasing the cuff pressure, and allowing the bloodflow fully to re-establish itself, the pain vanishes completely within 2 to 4 seconds.

Comment. The pain is due to something happening in the arm working without blood supply. It is a change that is stable while the blood supply is stopped, but which is quickly dispersed when a full bloodflow is restored.

[1] See *Heart*, vol. 15, 359.

31b. *Arterial arrest increased.* Repeat the exercise, with a cuff on each arm, but first stopping the bloodflow to one arm for 5 minutes, while the arm is kept at rest. Then cut off the bloodflow to the second arm and begin and continue to exercise them simultaneously.

There will be no pain in the arm to which the circulation is first cut off until after work is started, and it will begin in the two arms at much the same time and will increase equally in the two.

Comment. The pain is not the direct result of, and is not materially contributed to by, simple loss of blood supply. Work is required to produce it.

31c. *Muscular work increased.* Repeat the exercise, using both arms, but gripping once a second with one hand and once in two seconds with the other. The pain will develop in about half the time with the faster rate of movement. It will develop with a certain number of movements, whether the rhythm is slow or fast, provided the grips are equal.

Alternatively, maintain the same rhythm with the two grips, but grip more firmly with one hand than the other, and the pain will come first in the arm that works the harder.

Comment. The pain is related to the energy expenditure of the muscle deprived of blood supply.

31d. *Pain from the contracting muscles.* Shut off the circulation to an arm and, instead of contracting the muscles voluntarily, apply a continuous faradic current to the muscles of the thenar eminence. For this purpose use a $\frac{1}{2}$ inch copper disc covered with saline moistened wash leather for the thenar region and use as the second electrode a large moist pad on which the forearm rests.

Use a current strength which keeps the short muscle of the thumb contracted, and maintain it until pain becomes

uncomfortable ; note that the pain continues and is in the thumb after the electrode is removed and that the ball of the thumb is a little tender. Release the arm.

Comment. The pain and tenderness are found in the region of the muscle that works, because the muscle concerned is the source of the pain.

31e. *Latent pain.* Use the gripping movement of the hand at the rate of 1 a second and continue the movement for 2 minutes (120 grips). Stop the movement, and at once shut off the circulation to the arm. There is at first no pain in the arm, but, if the cuff is not released, pain will appear within 20 or 30 seconds and may become severe.

Alternatively, work the arm with the bloodflow arrested until pain is considerable, then stop the work and simultaneously release the cuff pressure. The pain will vanish when the cuff pressure is released but it will come back again, without further work, if the cuff pressure is re-imposed. The pain will come back the quicker, and will develop the more strongly, the sooner cuff pressure is re-imposed.

Comment. The pain is supposedly due to metabolic processes occurring primarily in the muscle fibre, probably the accumulation of a given metabolite ; this brings corresponding change in the spaces between the fibres where pain nerves and blood vessels lie. In the presence of circulation the interstitial change (pain factor) is kept at a low level, and pain is absent or inconspicuous ; but, if the circulation is stopped, the interstitial pain factor rises with that in the muscle, and pain comes at the appropriate level. Lastly, if the circulation is stopped when there are accumulated metabolites in the muscle, there will be a gradual rise in the spaces and pain will come as a delayed phenomenon.

31f. *Recovery dependent on freedom of circulation.* Use the two arms, exercising both until pain is well developed in the

two ; then with a finger stop the brachial artery above the cuff (or the subclavian) in one arm and release the pressure in both cuffs. The pain will disappear from both arms, but it will disappear more slowly from the arm in which the artery is still obstructed. Estimate the rate of return of bloodflow to this arm by watching the colour of the hand. The pain will go the sooner the flow returns through variable collateral channels.

Comment. The rate at which the pain factor in the muscle is dispersed depends on the freedom of the returning blood-flow. It can also be shown to depend on the oxygen content of the returning blood, being slower if the subject is rendered anoxaemic before the release.

Application

Precisely similar pains are experienced by patients suffering from grossly defective circulation in a limb, a common condition. Usually it is a leg, and the result of obliteration of the lumen of the popliteal artery by disease. Such patients experience pain after walking a given distance (pain that is reproduced in all its detail when a subject walks with one leg tied off below the knee by a tourniquet) ; this pain is relieved if they rest ; a similar condition in horses occasions transient limping (intermittent claudication).

When the blood supply to the leg is so diminished that there is only enough blood flowing to keep the resting muscle alive, pain while walking will come as quickly in the unsound leg as in the normal leg robbed of its whole blood supply by a tourniquet. The amount of work which the muscles of the calf can do without pain is a useful guide to the degree of arterial damage, so is the speed with which the pain is relieved by rest once it has developed. There are other causes of pain on walking, but this pain of muscular ischaemia is recognised easily, because tenderness develops in the

muscle used, and if resisted dorsiflexor movements are substituted for the plantiflexor movement of walking, the pain and tenderness now come on the front and not on the back of the leg.

An understanding of the pain here described is also important because anginal pain results similarly when blood-flow to the heart is inadequate to meet the energy expenditure of this muscle at the moment.

32. EFFECTS OF CIRCULATORY ARREST TO A LIMB

The effects of circulatory arrest to a limb are many.[1] They include colour and temperature changes, and transient functional derangements of sensory and motor nerves ; the first two will be observed in the early and the last two in the later stages of arrest.

32a. *1st period of 5 minutes.* Use a pneumatic cuff on the upper arm of the subject and, while the arm and hand are warm, throw a pressure of 200 mm. Hg into the cuff and maintain it. The subject should understand that his arm may ache uncomfortably if it is not kept quite flaccid and still. Now the result of this procedure is to arrest the circulation almost but not quite completely ; a very little fresh blood finds its way through the cuff by nutrient vessels in the humerus and re-enters the main arteries of the forearm below the cuff. The trickle of blood, for it is no more, moves on the arterial blood column in the radial and ulnar arteries ; it makes little difference to the events witnessed. Complete arrest can only be obtained by distending the cuff over the elbow joint.

[1] For fuller information refer to *Heart*, vol. 16, 1 ; and the author's *Vascular Disorders of the Limbs*, London, 1936.

From the time that the circulation is arrested, the temperature of the limb begins to fall. In a room at 24° the temperature of the originally warm fingers will decline for some time at the rate of about 1° C. in 3 minutes; the temperature of the forearm, which has a smaller surface relative to its mass, will fall at about half this rate. Thus, within 5 minutes, the cooling that has taken place in the fingers will usually be distinctly perceptible to an observer's own fingers. The observer can readily detect a difference of 1° C. by making brief contact between the backs of his own warm fingers and those of the subject's fingers (right and left) to be compared.

Note also that during the 5 minutes the skin of the subject's limb is gradually becoming bluer in colour, until by the end of that period it will be violet and no longer changing. (The rate of change is slower in a cold limb; see 17a.)

When the cuff is on the upper arm, it is usual to see a few small islets of redder colour persisting, or even appearing, near the wrist and on the back of the hand. These are due to the trickle of blood through the humerus forcing blood on through the arteries of the forearm; they do not appear if the cuff is around the elbow.

32b. *2nd period of 5 minutes.* Sometimes during the first period, and more often in the second, some whitish patches will appear on the back of the hand or on the forearm. These become more prominent and tend to enlarge as time passes; their edges are often remarkable for their sharp definition. The general tendency of the vessels of the skin is to dilate during the arrest (see 22f); but there is an obscure and conflicting process, which often takes local precedence during the actual period of arrest, and is responsible for these white spots. The same process is responsible for the blanching which occurs in the skin of the body generally after death.

32c. *3rd period.* About the 13th to 15th minute functional changes begin in the nerves of the limb, and the first change noticed is numbness at the very tips of the fingers. By the 16th to 17th minute numbness has spread to reach the bases of the fingers and about the same time touch sense is quite lost in the finger tips. The numbness, succeeded by anaesthesia, continues to spread up the arm at the rate of a few centimetres a minute, until at the end of the half hour the whole arm below the cuff is anaesthetic.

As the skin loses its sense of touch the fingers become a little sore and pinching the end of a finger may hurt. But very soon pain sense begins to decline and, though this decline is always later than that for touch, it follows the same centripetal course up the arm.

The motor nerves supplying the muscles of the thenar eminence begin to fail about the 20th minute ; voluntary movement in them is paralysed at the time when anaesthesia has reached the wrist ; though the application of a faradic current will still cause them to contract. The extensors of wrist and fingers are paralysed at about the 30th minute, producing " wrist drop."

The arrest should not in general be allowed to continue beyond the 30th minute, though this is actually well within the margin of safety.

32d. *Events at the release.* Be ready to make observations quickly, and release the circulation. The whole limb below the cuff will flush brightly red (see 22a), but pay heed, not to this, but to the order of nerve recovery ; for this is very rapid and will be almost complete within $\frac{1}{2}$ to 1 minute of release. Notice that the order of recovery is the reverse of the order of paralysis in each instance. The recovery is of proximal and then of distal function; the last recovery is from numbness of the finger tips.

Circulatory arrests of this duration are followed on release

by uncomfortable pins and needles in the extremity of the limb, lasting for several minutes, but always passing away. You may be able to observe, as the limb warms with the inflow of fresh blood, that the fingers warm up more quickly and often to a higher point than the arm.

32e. *Sense of position lost.* You will scarcely have time during the progress of this main observation to notice, without repeating it, that sense of position in a finger is lost as it becomes anaesthetic. If the observer bends such a finger, the subject is unaware if it is bent or straight. Similarly the sense of position of the hand is lost when tactile sense has vanished to about the level of the wrist.

32f. *Comparing complete and partial arrest.* In a fresh observation compare the effect of arresting the circulation to one limb by pneumatic cuff and in the other by compressing the brachial artery with the finger. In the latter case the fall of temperature in the fingers is much slower, the difference being usually obvious within 10 minutes at ordinary room temperature. Also notice that brachial compression fails to produce notable cyanosis. These modifications of the effect of arrest are due of course to the functioning of anastomotic channels.

Comment. It is known that all the effects on nerves here described are due to loss of circulation to these nerves and not to pressure upon them, Some of the evidence for this statement is to be found in the following test.

32g. *Grade of pressure immaterial.* Throw a pressure of 150 mm. Hg onto one upper arm and 300 onto the other. Numbness will appear in the right and left fingers simultaneously. Do not compare the two arms if one has already suffered prolonged arrest of circulation to it on the same day.

32h. *Proximal and distal compression.* Place two cuffs, one above the other on one arm, blow up the bottom one and, when numbness is just distinct at the finger tips, blow up the top one and at once release the lower. This will not relieve the numbness, although the pressure is transferred to a different stretch of nerve ; that is so because the circulation remains arrested to the old stretch.

Now repeat the observation on the other arm, but first distend the upper cuff, and release it after distending the lower one. This will give immediate relief of numbness in the finger tips, because blood returns to the stretch of nerve originally deprived of it under the upper cuff. The reason why numbness occurs more readily when nerve is compressed proximally rather than distally still remains hypothetical.

32i. *Influence of temperature.* The rate at which the nerve is affected by asphyxia varies with temperature. Immerse the two arms to the middle of the upper arms in water at $25°$ and $35°$ for 10 minutes. Now place cuffs around the two elbows and stop the circulation to both arms. Numbness will appear about 3 minutes earlier in the arm that has been kept warm.

Application

All of the phenomena here described and that appear during arrest of bloodflow to a limb are encountered in cases in which bloodflow is arrested by thrombotic occlusion of the main artery of a limb. The present exercises permit the investigation of these phenomena in your own person and bring an understanding of them ; you will thus be able more readily to recognise what has happened in the patient and even to estimate approximately the time at which the occlusion has occurred. When a leg " goes to sleep " while you are sitting in a chair, this is due to pressure on the nerve which is in this way deprived temporarily of its blood supply.

The substances here included can be administered in the manner and dosage recommended with safety to normal young subjects.

In observing the general effects, the subject should lie in a warm room comfortably on a couch, stripped to the waist, and, if sweating is expected, in shorts with a large towel or blanket around the upper parts of the body. A preliminary period of 10 or 15 minutes quiet is usually necessary to ensure resting values for pulse, blood pressure, and respiration. These should be recorded until they have reached and remain at appropriate levels. If a rapid reaction of pulse rate is expected, it should be recorded graphically in a continuous tracing. If colour change is expected daylight is essential, and the precise extent of the more highly coloured skin should be observed carefully and marked out before starting an experiment. If a number of events is expected to occur rapidly, more than one observer is required ; there should not be a number of onlookers, observations should be as unobtrusive as possible in the circumstances, because it is important that the subject should be unperturbed though entirely cooperative. Where there is any apprehensiveness, pulse and blood pressure will suffer disturbance from this cause. When an injection is to be made, the syringe should be held ready for a minute or more after the needle has been inserted and, if it can be done, the injection should be made without the subject being aware of it.

33a. *Pilocarpine subcutaneously.*[1] In addition to the preliminary observations already mentioned, note the number of times that the eyelids blink and the number of swallows per

[1] See *Heart*, vol. 6, 299.

minute without attracting the subject's attention to these activities. The skin should be examined too to observe its state of dryness or moisture.

Pilocarpine nitrate is injected in a dose of 1·2 mg. per stone weight (namely, 12 mg. to 10 stone), beneath the skin of the upper arm and the effects observed.

Sweating will begin 5 to 15 minutes after the injection ; it comes on the head and neck, and especially on the central parts of the face, and it will spread to trunk and limbs, becoming universal in most instances. The reaction has declined greatly within 1 hour.

Salivation. The subject becomes conscious of increased salivation. This is indicated objectively by the rate of swallowing, which rises from about 3 swallows (in 5 minutes) to about 15. It is at its height about 15 to 20 minutes after injection and then declines, though some wetness of the mouth may be noted by the subject for several hours.

Lacrymation. Excessive secretion is constant, and is usually obvious 5 minutes from the injection, giving blinking and unusual glistening of the eyeball. A collection of tears almost to the point of overflow is not uncommon.

Goose skin. This phenomenon is frequent at the height of the reaction and is usually accompanied by slight shivering. It subsides within the hour.

Pulse, blood pressure, and respiratory rate. These show no constant changes with the dose recommended.

33b. *Amyl nitrite inhaled.*[1] The subject holds a rubber tube, about an inch in diameter, lightly but closely between the lips and at a signal takes a single long inspiration through it while 0·5 c.c. of amyl nitrite is injected into the lumen of the tube. The tube is at once removed and natural nasal breathing resumed.

[1] See *Heart*, vol. 6, 311.

The reaction begins in 10 or 15 seconds and rapidly becomes full. Time its onset from the injection by stop watch; it gives a measure of circulation time from lungs to face. The facial flush is usually vivid; it may be confined to the face, but often spreads to the neck and to the upper part of the chest. In general it is most conspicuous on parts that are already particularly coloured and usually spreads throughout these. A glass slide pressed on the flushed skin will usually detect capillary pulsation. Respiration is little affected, falling more often than rising in rate; it may be disturbed by coughing. The pulse rate rises 20 to 40 beats above its resting rate; systolic blood pressure falls 10 to 40 mm. Hg. The subject experiences a sense of fullness, tension, and throbbing in the head, which may rise to un-pleasant intensity but subsides within a minute. Palpitation is not usually felt with the dose recommended, and headache is infrequent as a sequel.

The reaction is over within $1\frac{1}{2}$ minutes of the inhalation, with this dose; it lasts longer and is more striking with twice this dose, which may be given to those who react poorly to the smaller one.

33c. *Atropine intravenously.*[1] In addition to the usual preliminary observations, attention should be paid to the irregularity of the pulse with deep breathing, and the size of the pupils should be noted in millimetres. Note also the rate of blinking and of swallowing.

Use a dose of 0·12 mg. of atropine sulphate to each stone of body weight (namely, 1·2 mg. to a 10 stone subject) and give it intravenously. After entering the vein wait for a few minutes to be sure that anticipation is not influencing the pulse and then inject slowly without informing the subject. The pulse rate rises to its maximal point usually within 2

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[1] See *Heart*, vol. 6, 293.

minutes of the injection, the rise is 20 or 30 beats per minute, actual rates attained being usually 105 to 120. The increased rate is a lasting one ; it is usually declining at the end of a half hour.

Under atropine the pulse rate remains unchanged, however deeply the subject breathes.

If a standard exercise (such as walking quietly down and up a flight of 60 stairs) is taken before atropine, and during the height of the reaction to it, it will be found that the heart rate rises by quite as many beats under the atropine as without it, and thus attains a much higher rate in the first circumstance. The rise of rate to exercise is largely independent of change in vagal tone.

Full atropinisation gives a heart rate of about 140 beats per minute. It is not obtained except with doses too high to be suitable for class work, namely, double or treble that here recommended.

Changes in blood pressure and respiration are insignificant. Dryness of the mouth is the rule and the rates of swallowing and blinking are reduced. The pupil occasionally shows distinct dilatation but this is not usually noticed until some hours after the injection.

33d. *Atropine in conjunctiva.* The direct effect on the pupil should not be tested in elderly subjects, nor in any subject who has experienced inflammatory eye trouble. To obtain a decided reaction of the pupil, place a few drops of 1% homatropine hydrobromide within one conjunctival sac, and repeat the drops 15 minutes later. At 30 minutes the widening of the pupil will be quite obvious ; it is full within an hour, but it takes very many hours to decline.

Use the opportunity thoroughly to examine the fundus with the ophthalmoscope. Make a habit of placing a few drops of 1% eserine salicylate in the conjunctiva to counteract the homatropine effect before releasing the subject.

33e. *Histamine intravenously* [1] *(and circulation times).* This substance should not be given to asthmatics or to women during menstruation. Histamine phosphate is used, the dose being 0·1 c.c. of a 0·1 solution per stone weight, given sub-cutaneously (namely, 1 c.c. or 1 mg. to a 10 stone subject). Ideally this solution should be buffered before use ; it is an acid solution and occasionally causes pain on injection. Similar results are obtained by injecting a tenth of this dose intravenously and quickly.

If given intravenously at the elbow an abrupt and peculiar feeling, or taste, is experienced at the back of the mouth after injection ; this marks the time when the substance reaches the tissues of the throat and may be used to estimate the circulation time from vein to throat ; it should be noted accurately by stop watch ; thus " arm to tongue " time is 10 to 15 sec. normally.[2] It is more reliable than the beginning of the flush, which, though often appearing about 15 or 20 seconds after intravenous injection, may be longer delayed. The flush comes to its height at about 1 minute in the intravenous and about 4 minutes in subcutaneous injection. (The last value indicates how quickly some substances are taken up by the vessels of the subcutaneous tissues.) The flush in the latter lasts a half hour, in the former 5 minutes or less.

The flush affects the same areas as does amyl nitrite, but also visibly includes the backs of the hands. A rise of temperature of several degrees can be registered in face and hand. The pulse rate rises 10 to 25 beats per minute ; both

[1] See *Heart*, vol. 13, 381.

[2] Many other substances have been used in preference. Saccharine (2 g. in 2 c.c. water) injected provides an abrupt taste of sweetness ; sod. dehydrocholate (5 c.c. of 20%) gives an abrupt bitter taste ; magnesium sulphate (5 c.c. of 10% solution) gives a hot sensation in the throat, followed sometimes by similar sensations in the limbs. The arm to lung time may be estimated by injecting 0·3 c.c. of ether in 1 c.c. of saline ; the time taken being to the detection of ether by patient or observer as it is exhaled. The normal time is 4 to 8 sec.

the systolic and diastolic blood pressures fall, the former about 5 mm. in the average, and the latter about 10 mm. Hg.

The subject experiences a sense of warmth and tension, especially of the head and neck, shortly after the injection ; and he acquires a characteristic headache, especially after intravenous injection. The headache begins 1 minute after the injection and lasts 5 to 10 minutes. It is at first in front of the head, spreading to vertex and occiput. Like many headaches experienced by patients and especially in migraine, if often throbs. It has been shown [1] to be associated with the decline of a preliminary rise of cerebrospinal pressure ; it is relieved by congesting the veins returning from the cranium ; these are some of the evidences that it results from change in intracranial tension, probably meningeal tension.

The action of histamine on the skin by pricking it in may be studied as described (see 19e).

33f. *Pituitary extract.*[2] If infundin is used, inject it intravenously in a dose of 0·05 c.c. ($\frac{1}{2}$ unit) diluted in 3 c.c. saline, or subcutaneously in a dose of 0·5 c.c. (5 units). Infundin, being a total extract of the gland, should not be given to women during menstruation. The pressor principle of pituitary gland may be used instead ; " petressin " is given in doses of 0·025 ($\frac{1}{2}$ unit) and 0·25 c.c. (5 units), respectively.

Subjective sensations are unusual with either form of injection, except that the intravenous often gives a peculiar feeling at the back of the throat as the substance arrives in these tissues. A little griping pain in the abdomen may be experienced by some subjects after some minutes.

The chief change observed is a very striking pallor of the skin, beginning about 1 minute after intravenous, or 3 minutes after subcutaneous, injection. It lasts $\frac{1}{2}$ to 1 hour or more. At its height the pallor may be so intense that all

[1] See *Clinical Science*, vol. 1, 77.   [2] See *Heart*, vol. 11, 353.

blood seems drained from the skin, and especially from those parts such as the face, which usually present most colour. The face becomes waxy in colour. Despite its intensity this pallor need cause no alarm. It is due to active contraction of the minute vessels of the skin. The heart continues to act vigorously and there is no evidence of comparable contraction of the arterioles, for the blood pressure (systolic and diastolic) rises no more than 10 mm. in the average. The pulse changes little in rate, respiration may become a little shallower.

The action of the substance on the minute vessels may be displayed by pricking it into the skin as described (see 18d).

33g. *Adrenaline intravenously.*[1] The reaction of normal subjects to intravenous adrenaline is of variable intensity ; if very obvious signs of its action are to be obtained, it is necessary to use doses of $\frac{1}{2}$ to 1 c.c. of 1 in 1000, and these are apt to be associated temporarily with very distinct discomfort. If it is used for class purposes the dose should be kept well below this level ; namely, at about 0·2 c.c. for a 10 stone subject. Even this dose will sometimes produce sensations of anxiety, a feeling of tightness in the chest, fullness of the head, giddiness, and palpitation. The subject often develops a little fine tremor. The dose is insufficient regularly to produce very obvious pallor of the skin ; but it raises pulse rate 10 or more beats per minute ; it lifts systolic blood pressure 15 or 20 mm., and the pulse pressure by about the same amount, thus exhibiting the main cardio-vascular effects of the substance. The effects subside within 3 minutes.

The action of adrenaline in causing active contraction of the minute vessels of the skin may be displayed as described (see 18d).

33h. *Adrenaline subcutaneously.* Take 0·2 c.c. of 1 in 1000

[1] See *Quart. J. Med.*, vol. 21, 459.

adrenaline hydrochloride, buffer it and dilute to 1 c.c. with normal saline. Inject the whole of this immediately, at two points side by side, under the skin of the front of the wrist. This injection will shortly blanch an area of skin in its neighbourhood ; later white streaks, sometimes branching and interlacing, will be seen extending for a variable distance up the forearm, exceptionally as high as the elbow. These white streaks mark the progress of the adrenaline up lymphatic channels in the skin. They are clearly due to the action of adrenaline upon the minute blood vessels of the skin, to which therefore it must diffuse from the lymphatics concerned. The lymphatics are not impervious channels but much of their content exudes into the surrounding tissue spaces, as it travels.

If the adrenaline is injected near to a vein, this vessel will be noticed to contract locally in response.

Notice that where blanching involves hair follicles the hairs are erected.

33i. *Acetylcholine intravenously.*[1] Injection of this substance gives uncertain effects, owing to its rapid destruction in blood. It may be used in doses to adults of 15 to 30 mg. of the hydrochloride, dissolved in 2 c.c. of normal saline. If this dose is introduced into the syringe and, after puncturing a vein, blood is first drawn into the syringe and the injection then made, little or no effect follows. To obtain the effect, no blood must enter the syringe and the injection must be made into a warm arm vein as quickly as possible.

The above dose then gives slowing of the heart within 10 seconds of the injection ; the effect lasts only for a few heart beats, and should be recorded graphically. A little later the face and neck flush, and the pulse quickens above its original rate. Sweating and lacrymation are not infrequent, nausea or actual vomiting are occasional.

[1] See *Heart*, vol. 16, 263.

Alternatively, the more stable substances carbaminoyl-choline chloride (" doryl ") in an intravenous dose up to 0·5 mg., or acetyl-B-methylcholine (" mecholin ") in an intramuscular dose up to 50 mg., may be used.

33j. *Electrophoresis.*[1] Bases such as histamine, adrenaline, etc., pass into the skin exclusively at the anode, namely, the electrode connected to the positive terminal of the battery.

Histamine. Make up a pair of non-polarisable electrodes. An amalgamated zinc rod is passed through a rubber cork into a glass tube 7 cm. long and about 1 cm. diameter ; this is filled with saturated zinc sulphate and its mouth plugged with kaolin. This non-polarisable electrode has previously
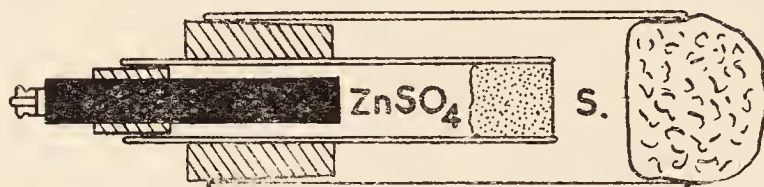

FIG. 8. Electrode for electrophoresis.

been passed through a second rubber bung ; which is now inserted into a glass tube of similar length and about 2 cm. diameter. The outer tube is filled with Ringer's solution, which may or may not contain a substance such as histamine. The mouth of the outer tube is closed by a thick plug of cotton wool saturated with the same solution.

Complete the circuit with key, variable resistance, micro-ammeter, and 8 volt accumulators. Fix the two electrodes mouths upward, introducing into that which is to be the anodal electrode histamine phosphate, in a dilution of 1 in 10,000 (= 1 in 30,000 base). Support the forearm so that its ventral surface lies lightly in contact with the two electrodes and pass a current for about 10 minutes. A current of 20

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[1] See *Heart*, vol. 16, 53.

microamp. (about 7 m.a. per sq. cm.) will produce local redness, a surrounding flare and a crop of local wheals.

Control observation. Repeat the observation without introducing histamine into the Ringer's solution, to determine that the result is due to the presence of histamine and not to injury by the current. 20 microamps passed for 10 minutes may (though usually it does not) produce a slight and transient redness of the skin. Distinct redness is produced with the histamine solution by a current of about 1/10 of this strength passed for the same period.

Adrenaline. Repeat the observation, substituting for histamine, adrenaline hydrochloride, 1 in 10,000, and pass a current of 20 microamps for 10 minutes. This will produce blanching of the skin over the area so treated.

Cocaine. Repeat using 1% cocaine hydrochloride and a current of 120 microamps for about 10 minutes. This treatment usually abolishes the pain response to needle prick, while touch though still felt is dulled. To abolish touch sense a longer application of a stronger current is usually required.